SOILS : THEIR CHEMISTRY AND FERTILITY IN TROPICAL ASIA

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by

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adapted from

SOILS : An Introduction to Soils and Plant Growth

by Roy L. Donahue

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DEDICATED TO

Prof. Dr. J. N. MUKHERJEE (1893 . . . .)

Whose life-long work and lively interest in Soil Science always inspired great zeal in Soil Scientists

and whose earnest and consistent efforts greatly advanced the cause of Soil Chemistry and its application for understanding and solving the intricate problems of soil fertility

FOREWORD

To my knowledge this is the first attempt at writing and publishing a textbook on soil chemistry and soil fertility for Tropical Asia. The time is very opportune because the region is developing rapidly in its agricultural research, education and production programs. There is no other region in the world where the pressure of population is so intense on so little naturally productive land. But neither is there any region that has a greater productive potential under wise scientific management. Most of the area has adequate rainfall, plentiful sunshine, and temperatures that never reach the freezing point. Although the soils of Tropical Asia are usually not as naturally fertile as soils of temperate regions, the relative cheapness and abundance of fertilizers and the remarkable response of most plants on most soils to the fertilizers help to compensate for their low fertility.

The problems are complex, however, for they involve the interactions of many crops to a complicated environment involving soils, fertilizers, water, pests and many other factors. Man has made great progress in his understanding of these relations and of how to change them. Where farmers have learned how to use this new knowledge, incomplete though it is, they have increased their production of crops, and often at the same time lowered the cost per unit of production. Some countries including the United States are now concerned with problems arising from the accumulation of huge surpluses of agricultural products. Most of Asia is now and for many years to come will be concerned largely with increasing her output of agricultural products. If she is to solve these problems she will require thousands of men who understand the relations between crops and soils, fertilizers, water, and pests. This book should contribute significantly to their understanding of these relationships.

Tropical Asia is now developing rapidly but will develop even more rapidly if more attention is given to a scientific study of the soils in relation to their formation, classification, and survey ; their physical, chemical, and biological properties ; the reclamation of acid, saline, and alkali soils ; and their response to fertilizers.

FOREWORD

This book provides the pertinent information on soil chemistry and soil fertility, in easily understandable form, necessary for a more rapidly expanding agricultural development in Tropical Asia.

RICHARD BRADFIELD

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PREFACE

College students in Tropical Asia perhaps know more about agriculture in the United Kingdom and in the United States than they do about agriculture in their own country. One reason for this anomalous situation is because many of their Instructors were educated abroad ; another reason is because almost all of the reference books and textbooks were written by Englishmen and Americans primarily for their respective country.

When a representative of Prentice-Hall first informed me that my American Textbook, "Soils : An Introduction to Soils and Plant Growth," written before I had come to India, was approved for reprinting in India in a low-cost edition, I replied, "Please don't; let me get a team of co-authors to adapt it for India." This request was granted.

In choosing co-authors I wanted a man who was at present teaching the course for which this book was written; this was D.P. Motiramani. Then I wanted an outstanding senior soil scientist; R.V. Tamhane was selected. Lastly, I wanted soil scientists, who had a good reputation for putting together scientific Indian English and who had taken many photographs of soil profiles; Y.P. Bali was the man.

Although all authors are Indians and we at first attempted to adapt the book only for India, we decided that with just a little more effort we could adapt it for Tropical Asia. That extra effort was expended. Now we have a book that we hope will be useful as a textbook and as a reference book throughout Tropical Asia, and I thank my co-authors sincerely for their excellent and timely cooperation in its preparation. I am certain that Instructors and students in Tropical Asia will be for ever grateful to them for this pioneer work.

Perhaps this is just the beginning of a long list of textbooks that are to be adapted or written for use in the Tropics. Especially needed are more books on Agriculture, Animal Husbandry, and Veterinary Science that will assist in increasing production of food, feed, and fibre for a region where the crop yields per acre are among the lowest and where the density of population is the highest in the world.

Acknowledgement for the source of photographs and data used is given after each caption or explanation ; where no acknowledgement is given, the source is one of the co-authors. Courtesy credits for the second page of the

Frontispiece, showing deficiency symptoms on maize are : Nos. 1,3,4,— National Plant Food Institute, Wash. D.C. ; and No. 2—Ray Cook, Michigan State University, U.S.A. In Tropical Asia, since Oxford spellings are more common than American spellings, the former have been used. A few non-English words have been used because they are very common in the Indo-Pakistan sub-continent. For the benefit of readers outside this area, these words with their Latin and English equivalents follow :

arhar—pigeon pea *(Cajanus cajan* or *Cajanus indicus)*

bajra—pearl millet *(Pennisetum glaucum* or *Pennisetum typhoideum)*

bunds—terraces

ghats—high hills or low mountains

groundnut—peanut *(Arachis hypoguea)*

hulga—horse gram *(Dolichos biflorus)*

jowar—sorghum; great millet *(Andropogon sorghum* or *Andropogon vulgare)*

kankar—calcareous nodules

marua—finger millet *(Eleusine coracana)*

masoor (masur)—lentil *(Lens esculenta* or *Lens culinaris)*

matki (moth)—kidney bean *(Phaseolus acontifolius)*

moong (mung)—green gram *(Phaseolus aureus)*

murram (murum)—gravelly and/or stony substratum

nalla—a natural channel for carrying water; usually applied to a dry or intermittently wet and dry drainage channel

paddy—rough rice; unhulled rice

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INTRODUCTION

The Agricultural Colleges in India have for long needed a textbook on soil fertility written with a bias for Indian conditions. Here is the first of such a book, designed for use in soil chemistry which is normally taught in the third or fourth year of Agricultural Colleges. It was written by a team of Indians consisting of Dr. R.V. Tamhane and Mr. Y.P Bali, Advisor and Assistant Advisor, respectively, to the Government of India on Soil Conservation, and by Dr. D.P. Motiramani, Professor of Agricultural Chemistry, who is currently teaching the specific course for which this textbook has been written; in collaboration with Dr. Roy L. Donahue, an American soil scientist who has been serving as a soils and fertiliser specialist in India for more than 7 years and who has also collaborated in writing books on "Soil Management in India" and "Agriculture in India".

This book represents the first attempt at adapting to India and other Tropical Asian countries the popular American textbook by Dr. Donahue on "Soils : An Introduction to Soils and Plant Growth." It has been so extensively rewritten, however, that it may be difficult to recognize any similarity between the two books.

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CONTENTS

SOILS : THEIR CHEMISTRY AND FERTILITY IN TROPICAL ASIA

Tropical Asia is characterised by a high density of population and very low yields per acre. *The result is hunger.* Increased yields of food grains can readily be obtained but requires a more liberal application of commercial fertilisers that are available within a few miles of each farmer Here is a depot in India where fertilisers are supplied on credit to farmers for growing rice.

Rice in Tropical Asia is the principal food grain but the production per acre is the lowest in the world , fertiliser used per acre is also the lowest. This demonstration in central India proves that yields of rice can be increased substantially by the proper use of fertiliser (*Courtesy Frank Shuman*)

Millions of children in Tropical Asia do not have enough to eat, but these children have no such worries because this hybird maize yielded 6,400 pounds of grain per acre. (Central India). To obtain such high yields, however, requires an adapted hybrid and adequate fertilisation, which is best obtained from a soil test.

(Courtesy Frank Shuman)

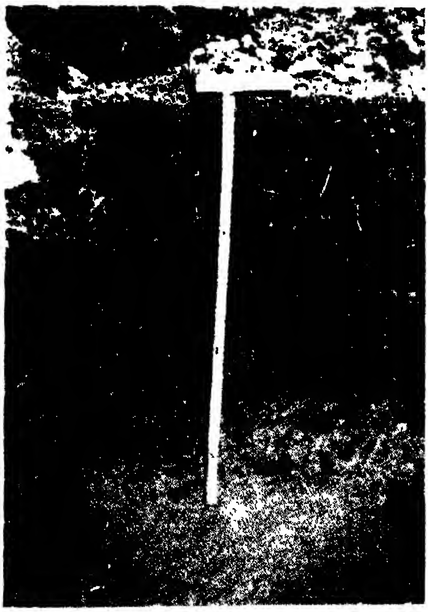
Wheat on black clay soil responds only *slightly* to N fertiliser, *greatly* to N P and the *best* to N P K The soil test was low in N, low in P and medium in K (India)

(Courtesy : Frank Shuman)

1 Young virgin soil developing over coral (calcium carbonate) deposits near seashore under mixed deciduous and evergreen forest vegetation, hot humid tropical climate with average annual rainfall of 130 inches. Leaf litter is small. Decomposed organic material has caused brownish colour of surface horizon (Location Little Andaman Island India.)

2. A lateritic soil profile (Latosol) Top three feet reddish soil lies over a quartzite layer underlain by whitish grey mica-schist. The soil formation process is probably ground water laterization. Location Sambalpur district, Orissa State, India

3 A black soil (Grumosol), developing from calcareous basalt parent material. The soils are highly clayey. (Location Nagpur district Maharashtra State India.)



4 A soil profile with high water-table under paddy culture. Variegated colours of different layers and reddish mottlings are clearly seen in the fluctuating water-table zone (2 to 6 feet depth) Presently the free ground water-table stands at 3 feet (Location Sambalpur district Orissa State, India.)

2

1. *Nitrogen* deficiency symptoms start with a yellowing of the tips of old leaves and progress along the midribs, causing V - shaped yellow areas **2.** *Phosphorus* deficien causes tips and margins of leaves to become reddish-purple especially in young plants **3.** *Potassium* deficiency symptoms start by the drying of tips and edges of lowest leav first, then progress upward **4.** *Water* deficiency causes the leaves to be grayish-green and to roll upward

CHAPTER ONE

SOILS AND PLANT GROWTH

> *"The crops on a field diminish or increase in exact proportion to the mineral substances conveyed to them in manure [fertiliser]"*
>
> JUSTUS VON LIEBIG, 1803—1873

Many definitions of soil have been made, some very long, some short. Here is a definition which is a combination of those given by Joffe and Marbut, two well-known American soil scientists.

> "Soil is a natural body developed by natural forces acting on natural materials. It is usually differentiated into horizons of mineral and organic constituents of variable depth which differ from the parent material below in morphology, physical properties and constitutions, chemical properties and composition, and biological characteristics."

The above definition is more descriptive than concise but three important characteristics of soil should be borne in mind : (1) natural formation (2) differentiation into horizons, and (3) morphological, chemical, and biological differences between parent material and soil horizons.

The soil is a natural medium for plant growth. Soil supplies nutrients for growing plants, and plants manufacture feed for animals and food and fibre for man.

Some soils are naturally productive and support luxuriant crops of great value with every little human effort, while other soils are so unproductive that they support almost no useful plant life regardless of what is done to them. Between these two extremes lie the majority of soils, which must be fertilised, irrigated, drained, or limed to make them desirably productive.

Productive soils are ones which contain adequate amounts of all essential elements in forms readily available to plants, are in a good physical condition to support plants, and contain just the right amount of water and air for desirable root growth. Not only must the soil contain the essential elements, be in good tilth for plant support, and contain the proper amounts of air and water, but it also must supply these essentials every day in the life of the plant.

Too little calcium even for a day may reduce crop yields. And if the soil is hard and crusty so that it is too wet after a rain and too dry a few days later, plant growth is stunted. To be more specific, all crop plants need the same kinds of elements in addition to water and air, but plants differ in the relative amounts of their requirements of these essentials. For example, *bajra*, lucerne, and rice all require the same elements, as well as air and water. But *bajra* grows on soils very low in both available nutrients and water, while lucerne requires a very fertile soil which is constantly moist. On the other hand, lucerne and rice both have a high water requirement, but lucerne must have plenty of air mixed with the water, whereas rice does better when the soil is flooded with water. (See Figure 1 1.)

I. COMPONENTS OF SOIL

The soil consists of four major components : mineral matter, organic matter, soil air, and soil water. Mineral matter forms the bulk of soil solids (by weight about 90 per cent). The chemists find that almost all of the elements that occur in nature are found in the soil. Most of the elements occur only as traces. By volume the air-dry soil contains 45-50 per cent mineral matter, air about 40 per cent, water 5-10 per cent, and organic matter 4 per cent.

Physically, the soil consists of stones, large pebbles, dead twigs, roots, leaves, coarse sand, fine sand, silt, clay, and humus—a dark organic substance. Clay particles usually form lumps or aggregates of varying sizes, by themselves or in association with organic matter.

The chemical composition of a typical clayey surface soil (locally called *manat*) from Maharashtra (India) is shown in Table 1.1. Silica makes up 56.6 per cent, iron oxide 15.2 per cent, and alumina 15.0 per cent. Following in order are lime 1.0 per cent, potash 0.75 per cent, phosphate and nitrogen content 0.038 and 0.1 per cent, respectively, and organic matter 1.33 per cent.

Approximately half of the organic matter consists of the dead remains of former soil life in all stages of decomposition, the other half is very much alive. The living part consists of plant roots, bacteria, earthworms, algae, fungi, actinomycetes, nematodes, and many other forms of soil life.

TABLE 1.1
CHEMICAL COMPOSITION OF *MANAT* CLAYEY SOIL
(MAHARASHTRA– INDIA)*

Constituent	Depth (Inches) 0–6	6–12
	per cent	per cent
Loss on ignition	11.86	10.12
Silica and insoluble silicates	56.60	67.86
Iron oxide	15.20	18.41
Alumina	15.00	11.99
Lime (CaO)	1.00	0.42
Potash (K_2O)	0.75	0.59
Phosphate (P_2O_5)	0.038	0.042
Nitrogen (N)	0.104	0.078
Organic matter	1.33	1.14

**Source* : Sahsarbudhe, D.L., *Agricultural Chemistry*.

Fig. 1.1 From the soil, plant roots receive mechanical support, essential elements, water, and oxygen for plant growth. In addition, legumes, as shown here, are capable of obtaining some nitrogen for their nutrition directly from the soil air. Note: Large numbers on the scale are in feet.) *(Courtesy Allan Prince)*

2. SOIL FACTORS INFLUENCING PLANT GROWTH

From the soil, plant roots receive mechanical support, essential elements, water and oxygen, for plant growth.

Some soils are in such a physical and chemical condition as to encourage plant roots to grow deeply and to extend long distances laterally. These soils are ideal because the plants growing in them will be wind-firm, drought-resistant, and capable of absorbing nutrients from a large volume of soil. Plant roots may be restricted by naturally or artificially compacted layers, infertile horizons, too much or too little soil moisture, or soluble salts in toxic quantities.

At present 16 elements are known to be essential for the growth of crop plants. They are carbon, hydrogen, and oxygen from air and water ; phosphorus, potassium, sulphur, calcium, iron, magnesium, boron, manganese, copper, zinc, molybdenum, and chlorine from the soil ; and nitrogen from both soil and air.

Water and air occupy pore spaces in the soil. Following a heavy and prolonged rain, the soil pores may be almost completely filled with water for a few hours. After a day or two some water will have moved downward in response to gravity, and the larger pores will be emptied of their water but filled with air. With a further loss of water by evaporation or transpiration, air will replace more of the water. The next soaking rain will repeat this process.

The important part of this air-water relationship is that there must be enough total pore space and that the pore spaces must be of the proper size ranges to hold enough air and water to satisfy plant roots between cycles of rainfall or irrigation.

3. EARLY CONCEPTS OF SOILS AND PLANT GROWTH

Xenophon, a Greek historian (430-355 B.C.), is credited with first recording the value of green-manuring crops when he wrote :

> " But then whatever weeds are upon the ground, being turned into the earth, enrich the soil as much as dung."

Cato (234-149 B.C.) wrote a practical handbook in which he recommended intensive cultivation, crop rotations, the use of legumes for soil improvements, and the value of manure in a system of livestock farming. Cato was also the first to classify land according to its relative value for specific crops.

His classification included :

1. Land for vineyards
2. Land for gardens
3. Willow land
4. Land for olive trees
5. Meadow land
6. Corn land
7. Timber land
8. Land for small trees
9. Land for oak trees

The usefulness of turnips for soil improvement was emphasized by Columella about A.D. 45. Liberal amounts of manure were recommended for turnips, and the turnips were to be ploughed under and the land planted to maize. Also advocated by Columella were land drainage, and the use of ashes, marl, clover, and lucerne to make the soil more productive.

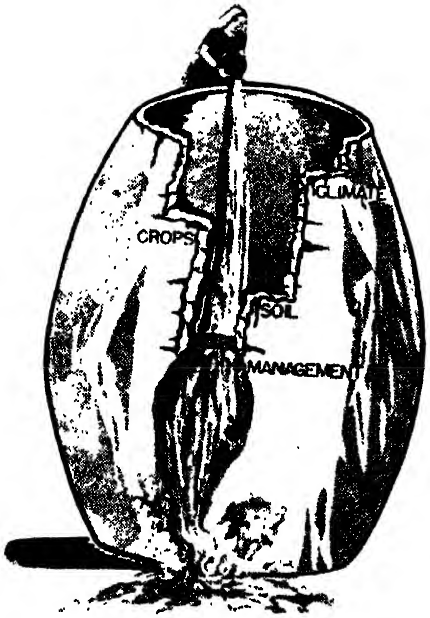
Then the barbarians of the north conquered Rome Scientific agriculture and other forms of art and culture were arrested until nearly 1600.

A classical experiment was performed by Van Helmont (1577-1644) in Holland. He put a five-pound willow tree in 200 pounds of soil (oven-dry basis) The tree received only water for five years. At the end of this period, the soil weighed only two ounces less than 200 pounds, but the willow tree weighed 169 pounds and three ounces. Since the tree was given only water, Van Helmont reasoned that water was the "principle" of vegetation. While Van Helmont's experiment was advanced for the times, his reasoning was later proved false on two counts :

1. The loss of two ounces of soil, which he ignored, consisted of minerals such as calcium, potassium and phosphorus, that were absorbed by the tree. If Van Helmont had burnt the willow tree at the end of the experiment, he could have recovered the two ounces of soil minerals.
2. The willow tree consisted of carbon from the carbon dioxide of the atmosphere, and oxygen from the atmosphere. The occurrence of carbon and oxygen from air as constituents of the willow tree refute Van Helmont's conclusion that water is the "principle" of vegetation.

In 1731 Jethro Tull of Oxford, England, concluded that cultivation was one of the prime essentials of growing plants, and that nitre, water, air, fire, and earth all contributed to increases in plant growth.

Justus von Liebig, a German chemist (1803-1873) believed that by analyzing crop plant ash he could formulate a fertiliser that would supply



THE LEVEL OF PRODUCTION CAN BE NOT HIGHER THAN THE LOWEST POINT

Fig. 1.2 An illustration of Liebig's "Law of the Minimum." The level of production can be no greater than the factor in most critical supply, shown here as "management". However, if "management" were improved to perfection, yields would not be at their maximum because of a second limiting factor, shown here as "soil". Correcting the soil factor would then make "crops" the limiting factor, then "climate". Thus, at any one time, only *one* factor limits the level of production. Liebig's original illustration was a wooden barrel with variable heights of staves each stave representing a plant nutrient element such as "Nitrogen", "Phosphorus", or "Potassium". At any one time, the nutrient element in least relative amount limited plant growth.

all essential elements for the next crop. He also developed the "law of the minimum" which stated that the growth of plants is limited by the essential element present in the least amount, as shown graphically in Figure 1.2. Liebig in 1840 published "Chemistry in its Application to Agriculture and Physiology." His thesis was that carbon for plant nutrition came from carbon dioxide of the atmosphere, hydrogen and oxygen from air and water, and nitrogen from ammonia. Phosphates were stated to be necessary for seed production and potassium for the development of grasses and cereals.

In 1843, the first agricultural experiment station in the world was established by J.B. Lawes and J.H. Gilbert at Rothamsted, England, a few miles from London. This experiment station laid the groundwork for modern research techniques in soils and plant growth.

About 1870 V.V. Dokuchaev in Russia developed a method of studying soils in the field in relation to their climatic, physiographic, and biotic environment. This was the basis for modern soil morphology, soil classification and soil survey.

Ewald Wollny in Germany during the years 1879 to 1898 conducted research on soil-plant-air-water relationships as they influence and are influenced by the physical properties of the soil and erosion. For this research Wollny may be considered "the father of modern soil conservation."

F.H. King of Wisconsin first published a book *Physics of Agriculture* in 1899, based largely on his own research work.

4. MODERN CONCEPTS OF SOILS AND PLANT GROWTH

Soil is a three-dimensional, dynamic, natural body occurring on the surface of the earth that is a medium for plant growth and whose characteristics have resulted from the forces of climate and living organisms acting upon parent material, as modified by relief, over a period of time.

Using modern methods of science, it is possible to study soil characteristics and the response to soil management practices, in the field, in the greenhouse, and in the laboratory. With the use of this information, soil maps can be made that permit accurate predictions of soil management responses in new areas that have similar soil characteristics to those soils where research had previously been conducted. It is not therefore necessary to conduct research on every acre of land to be able to predict crop responses to soil management practices.

Before the general availability of commercial fertilisers, farmers depended mostly on the natural nutrient supplying power of soils, supplemented by a small amount of farmyard manure, to grow farm crops. In most parts of Tropical Asia this condition still exists today.

Nitrogen, phosphorus, and sulphur in soils are constituents of organic matter. Approximately 95 per cent of the total soil nitrogen, 5 to 60 per cent of the total soil phosphorus, and 10 to 80 per cent of the total soil sulphur are present in the organic matter. These three nutrients become available to plants only after biological decomposition. The nutrient supplying power of the soil for nearly all of the nitrogen and for variable amounts of phosphorus and sulphur is therefore dependent upon the total amount of organic matter and its rate of decomposition in relation to the time that plants require these nutrients. Factors that favour organic decomposition are high temperatures, a favourable oxygen and moisture supply, and an abundant supply of nutrients that are required by bacteria.

In addition to organic matter decomposition as a source of sulphur to plants, rainwater returns to earth about 5 or more pounds of sulphur per acre per year.

The nutrient supplying power of sand and silt is very low because they are composed mostly of relatively undecomposed primary minerals. By contrast clay is composed of secondary weathered minerals (kaolinite, montmorillonite, and illite) and hydrous oxides of iron and aluminium, and therefore has a greater power to supply nutrients to plants.

Phosphorus is taken into the plant in the water-soluble form from the soil solution. The concentration of phosphorus in the soil solution is then replenished from slowly soluble forms such as calcium phosphate, hydroxyapatite, fluorapatite, iron phosphate, and aluminium phosphate ; and from the decomposition of organic matter.

Potassium occurs in the soil mostly as a constituent of primary minerals that exist in sand and silt particles. Such minerals as orthoclase and microcline release potassium slowly, but others such as muscovite and biotite are important sources of potassium, especially in tropical areas such as in Tropical Asia where temperatures and moisture are high. Some of the potassium that is released by the decomposition of minerals will stay in the soil solution and be available to plants and some will be adsorbed on the surface of clay and humus particles in a readily exchangeable and available form. Of the total potassium in a soil, approximately 1 per cent will be in the exchangeable form, and of this amount, from 1 to 5 per cent will be in the soil solution.

Calcium and magnesium in soils occur in both slowly as well as readily soluble minerals and rocks. Slowly soluble sources of calcium include oligoclase (a sodium and calcium silicate) and anorthite (a calcium alumino-silicate), whereas readily soluble sources include calcite and limestone. Slowly soluble sources of magnesium include augite, biotite, and hornblende. Readily soluble sources of both calcium and magnesium include dolomitic limestone. Calcium and magnesium are supplied to plants in ionic form in a manner similar to that of potassium, *i.e.*, from rocks and minerals to the soil solution and to an exchangeable form on the surfaces of clay and humus particles.

A close look at a fresh, productive loam soil will reveal that the soil is composed of lumps which are held together by fine roots. (See Figure 1.3).

Fig. 1.3 A close look at a handful of fresh, productive loam will reveal that the soil is composed of lumps which are held together by fine roots.
Left : Air-dry soil
Right · The same soil to which water has been added to bring it to the right moisture content for plant growth *(Courtesy Soil Conservation Service, United States Department of Agriculture)*

Upon closer examination with a 10-power hand lens and a 100-power microscope, these lumps of soil are also observed to be held together by fungal hyphae and the vegetative parts of actinomycetes. Shiny streaks on the soil lumps were probably made by the slimy secretions of earthworms. This slime, as well as the gums and resins remaining as temporary end-products of organic decomposition, are good cementing agents that help plant roots, fungi, and actinomycetes to glue the individual particles into desirable lumps.

Now imagine that a seed is planted in the handful of soil. Soon root hairs permeate the entire soil mass, following mainly along the crooked paths left by previous plant roots, earthworms, ants, fungal hyphae, and the vegetative parts of actinomycetes. (See Figure 1.4).

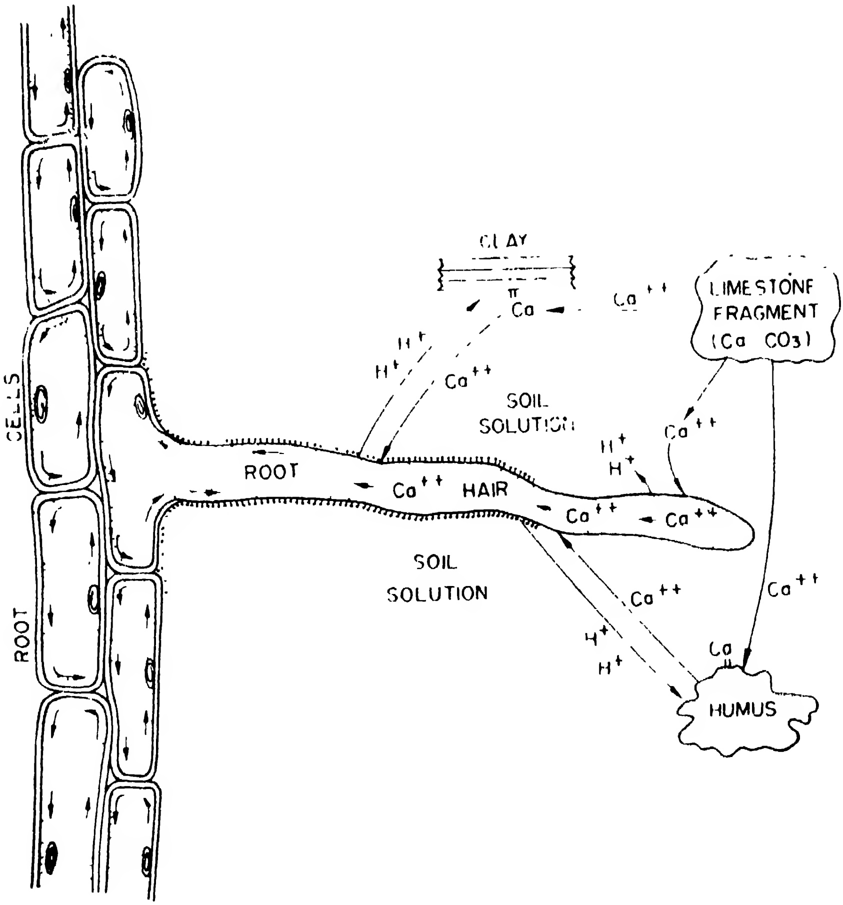


Fig. 1.4 Root hairs obtain nutrients required for the plants by an exchange of cations and anions between the surface of the root hairs and the surfaces of clay and humus particles, and from the soil solution.

The root hairs obtain nutrients by an exchange of cations and anions between the surface of the roots and the surfaces of clay and humus particles. There is also a similar exchange between the root surface and the soil solution. The root uptake of calcium for example, is accomplished by the release of two hydrogen ions from the root to either the soil solution or the surfaces of clay or humus, in exchange for one calcium ion from these sources to the root. Similarly, the plant root appears to exchange OH ions for nitrates, sulphates, phosphates and other anions. One difference in the plant uptake of cations and anions is the fact that most cations are on the surfaces of clay and humus, whereas most anions are in the soil solution.

5. SOIL FERTILITY AND NATIVE VEGETATION

Contrary to popular belief, many soils, even when virgin, were never plentifully supplied with all essential elements. Before the common use of lime and fertilisers, farmers would adjust to differences in native fertility by choosing the best virgin land, farming it until crop yields declined, then clearing other virgin land. This is the common practice even today in many underdeveloped countries where lime and fertilisers are not readily available.

Hilgard, one of the best early American soil scientists, in his book first copyrighted in 1906, made a shrewd observation on the relationships between native vegetation and soil fertility in the South (U.S.A.) when he wrote :

> " Thus in the long-leaf pine uplands of the Cotton States, the scattered settlements have fully demonstrated that after two or three years cropping with corn, ranging from as much as 25 bushels per acre the first year to 10 and less the third, fertilisation is absolutely necessary to further paying cultivation. Should the short-leaved pine mingle with the long-leaved pine, production may hold out for from five to seven years. If oaks and hickory are super-added, as many as twelve years of good production without fertilisation may be looked for by the farmer ; and should the long-leaved pine disappear altogether, the mingled growth of oaks and short-leaved pine will encourage him to hope for from twelve to fifteen years of fair production without fertilisation."

In India and in other Tropical Asian countries not enough is known on the association of soil fertility with vegetation. Alkali soils are however known to have characteristic vegetation. Slightly alkali soils are covered mostly with thick jungle of *Dhak* (*Butea frondosa*) and *Ronssa* with a

sprinkling of *Karaunda* (*Carissa spinarum*) and other bushes. There is also a thick undergrowth of tall grasses during the rainy season. Strongly alkali or *usar* soils are associated with short grasses. Very strongly alkali and saline soils are devoid of vegetation.

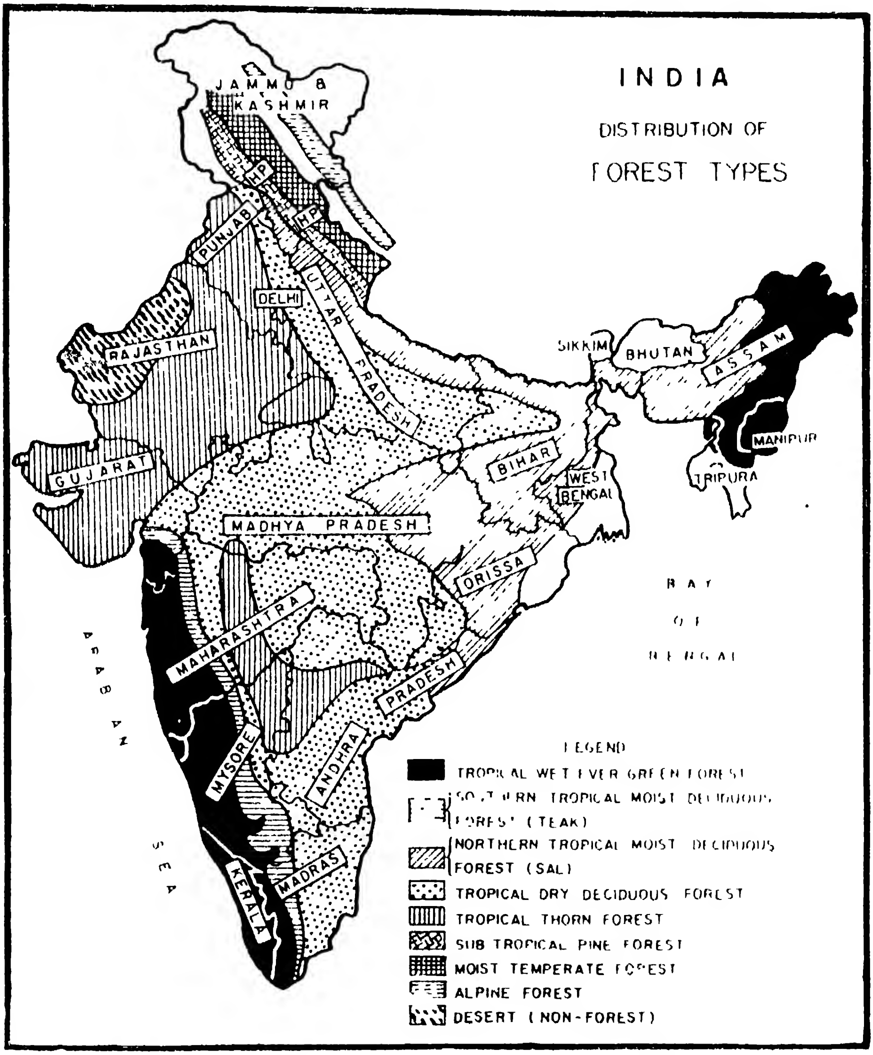


Fig. 1.5 A map of India showing the forest types.

A forest type map of India has been prepared and is presented in Figure 1.5. The general relationship between forest types and soils may be seen by comparing this map with the map of the soils of India in Chapter 5.

CHAPTER TWO

PHYSICAL PROPERTIES OF SOIL

Friable Soil for Tobacco "

ANCIENT TAMIL PROVERB.

The soil is a complex mechanical system consisting of three phases, viz., solid, liquid, and gaseous. The bulk of the solid phase, that occupies approximately fifty per cent of the total volume, consists primarily of the mineral materials and some organic matter, the latter being particularly high only in organic soils. The rest of the volume which makes up the pore space or voids is occupied by liquid and gaseous phases whose proportions vary reciprocally to each other and fluctuate considerably under natural climatic conditions and management practices. Thus the proportion of the four major components of soil--inorganic particles, organic matter, water, and air—vary greatly in different kinds of soil and from place to place and also with the depth of the soil. However, the four main components generally exist in an intimately mixed condition.

Physical properties (mechanical behaviour) of a soil greatly influence its use and behaviour towards plant growth. The anchorage that it provides to plants, penetration of roots, drainage, aeration, retention of moisture, and plant nutrients are primarily linked with the physical conditions of the soil. Physical properties also influence the chemical and biological behaviour of a soil.

The physical properties of a soil depend on the amount, size, shape, arrangement, and mineral composition of its particles ; kind and amount of organic matter; and the volume and form of its pores and the way they are occupied by water and air at a particular time. Some of the important physical properties of soils are texture, structure, density, porosity, consistence, colour and temperature.

I. MECHANICAL ANALYSIS AND SOIL TEXTURE

The mineral component constitutes the largest volume of soil mass and plays a vital role in determining most of the physical properties of soil. This mineral portion consists of particles of various sizes. According to the size, the soil particles are grouped into gravels, sands, silts, and clays which are termed as soil separates or fractions. The proportionate composition of various separates in a soil, which defines the soil texture, is determined by a mechanical analysis.

Mechanical Analysis : The process of determining the amounts of individual soil separates below 2 millimeters in diameter, that is, sands, silts, and clays, is called a mechanical analysis. It is one of the most important laboratory determinations made in soil studies.

During the mechanical analysis, the soil sample is first lightly crushed and screened through a 2 millimeter round hole sieve. All the rocks, pebbles, leaves, and plant roots that are retained on the sieve are discarded.

To get an accurate estimate of the percentage of individual soil grains of various sizes, it is necessary to destroy organic matter by treating the soil with hydrogen peroxide; to remove all other binding materials such as carbonates and oxides by treating with hydrochloric acid and washing; and to disperse the remaining soil material so that it can be separated into its individual mineral soil particles. In the absence of complete dispersion, the lumps or aggregates of clay of the same size as sand would be wrongly reported as sand in the results of mechanical analysis.

There are several methods of mechanical analysis, but only two have wide acceptance : The Pipette Method and Bouyoucos Hydrometer Method*. Both methods are based upon the differential rate of settling of soil particles in water, and the accuracy of the methods depends upon these conditions and assumptions :

1. Complete dispersion of the soil in water.
2. A dilute suspension of soil in water so that the soil grains can settle without bumping into or otherwise influencing each other.
3. All soil particles settle as if they were smooth and rigid spheres.
4. The rate of settling of the particles is assumed not to be influenced by the walls of the settling vessel.
5. A constant and known temperature of the soil-water suspension.
6. All soil particles are of the same density.

* For other current methods of mechanical analysis, consult V.J. Kilmer and L.T. Alexander, *Methods of making Mechanical Analysis of Soils*. Soil Science 68 : 15-24 ; 1949.

Soil Separates : A mechanical analysis reports the percentages of different size groups of particles. The size limits in diameter assigned to various groups are arbitrary. The two most widely-used size distribution systems are according to U.S. Department of Agriculture and International Society of Soil Science. Mohr,* while working with tropical soils, has suggested 10 fractions. The international system is commonly followed in India. A comparison of the three systems of classifying soil separates is given in Table 2.1.

TABLE 2.1
A COMPARISON OF THE THREE SYSTEMS OF CLASSIFYING THE SOIL SEPARATES

U.S. Dept. of Agriculture System		International System		Mohr's 10 Fraction System*	
Soil Separate	Diameter Range (mm)	Soil Separate	Diameter Range (mm)	Soil Separate	Diameter Range (mm)
1 Very coarse sand	2.00–1.00	1 Coarse sand	2.00–0.20	1 Very coarse sand	2.00–1.00
2 Coarse sand	1.00–0.50	2 Fine sand	0.20–0.02	2 Coarse sand	1.00–0.50
3 Medium sand	0.50–0.25	3. Silt	0.02–0.002	3 Medium sand	0.50–0.20
4. Fine sand	0.25–0.10	4. Clay	Below 0.002	4 Fine sand	0.20–0.10
5. Very fine sand	0.10–0.05			5 Very fine sand	0.10–0.05
6 Silt	0.05–0.002			6. Coarse silt	0.05–0.02
7 Clay	Below 0.002			7 Silt	0.02–0.005
				8 Fine silt	0.005–0.002
				9 Clay	0.002–0.0005
				10 Colloidal clay	Below 0.0005

* Mohr, E. C. J. & Van Baren, F. A. *Tropical Soils*. Interscience Publishers Ltd., London New York, 1959.

According to Mohr* and Dames†, the ten-fraction scale is found more suitable for tropical soils as some typical differences between soil types are clearly demonstrated. This advantage is especially shown by the finer fractions 8, 9, and 10. In Indonesia, it has been shown that margalite soils have a pronounced 9th fraction while the 10th fraction is more pronounced in lateritic soils. (Table 2.2) (See Figure 2.1).

* Mohr, E.C.J and Van Baren, F.A., *Tropical Soils*. Interscience Publishers Ltd., London, New York, 1959.

† Dames T.W.D. *Some notes on the Soil Survey of Java*. Commonwealth Bureau of Soil Science, Technical Communication No. 46 ; 115-120, 1949.

TABLE 2.2

EXAMPLES OF SOILS HAVING THE SAME PERCENTAGE OF SEPARATES BELOW 0.002 mm FRACTION, BUT SHOWING DIFFERENT PERCENTAGES OF SUB-FRACTIONS*

Soil and Locality in Indonesia	Below 0.002 mm in % (9th + 10th fractions)	0.002—0.0005 mm in% (9th fraction)	Below 0.0005 mm in % (10th fraction)
Lateritic soil, Priangan, Java	55	14	41
Margalitic soil, Madioen, Java	53	30	23
Lateritic soil, Rembang, Java	49	12	37
Margalitic soil, Semarang, Java	50	30	20
Lateritic soil, Bontaeng, Celebes	37	11	26
Margalitic soil, Semarang, Java	37	22	15

* Mohr, F.C.J and Van Baren, F.A., *Tropical Soils* Interscience Publishers Ltd., London. New York, 1959.

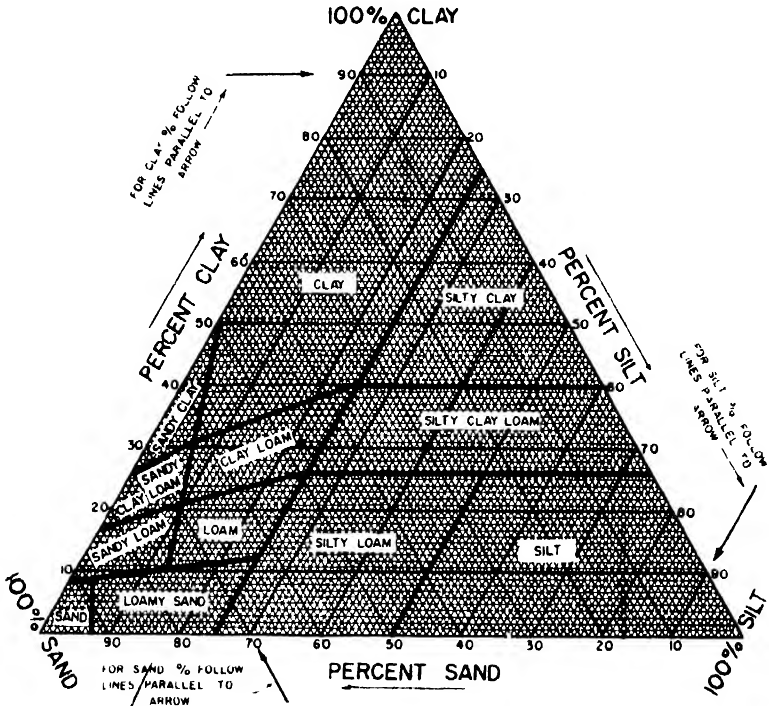


Fig. 2 1 Guide for Textural Classification by the International System for Textural Designations.

Source. Marshall, T. J., *Mechanical Composition of Soils in Relation to Field Description of Texture* Commonwealth of Australia, Council for Scientific and Industrial Research, Melbourne, Australia, Bulletin 224, p. 20, 1947.

2. PHYSICAL NATURE OF SOIL SEPARATES

Physical properties of soil are dependent mainly on total surface area exposed by soil particles, although the chemical properties of the particles and organic matter content also exert influence. Surface is primarily a function of the size of the particles. Surface area in square centimeters per gram or per cubic centimeter of soil is called *specific surface* of the soil.

Sands consist of original resistant minerals and are large sized, expose little surface, are mainly inactive and primarily constitute the framework or skeleton of the soil mass. Clays consist principally of secondary products of chemical weathering, have ultramicroscopic size, expose extremely large surface area, are very active fractions of soil, and influence most of its physico-chemical properties. With decreasing particle size of clays, there is an increase in surface area, and the properties such as swelling, plasticity, cohesion, and adsorbing power also become increasingly prominent. Silts show properties somewhat intermediary between sands and clays and are composed mainly of original mineral fragments

It has been roughly estimated that the total surface area exposed by one cubic foot of sand is approximately one half acre ; that of loam is about 10 acres ; and that of clay is nearly 100 acres *

3. SOIL TEXTURE

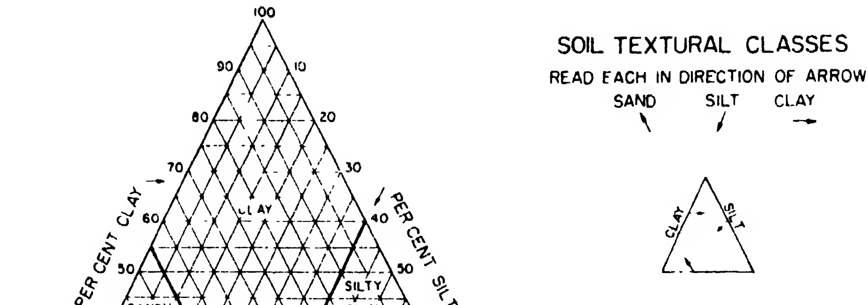
Soil texture refers to the relative percentage of sand, silt, and clay in a soil. Natural field soils are always mixtures of soil separates. The relative percentages of the various soil separates in a field soil are almost infinite in possible combinations. It is, therefore, necessary to establish limits of variations among the soil separates so as to group them into textural classes, such as sandy, silty, loamy, and clayey. The size of the sand grain such as "fine" or "coarse" further modifies the textural name. The limits in the range of each textural name have been established upon significant differences in the physical properties of each textural class. The more common textural classes listed in order of increasing fineness are :

Sands	Sandy Clay Loam
Loamy Sands	Clay Loam
Sandy Loams	Silty Clay Loam
Loam	Sandy Clay
Silt Loam	Silty Clay
Silt	Clay

For convenience in determining the textural name of a soil from the

* U. S. Dept. of Agriculture "*Forest Service Handbook—Handbook on Soils*", Washington D.C., 1960.

mechanical analysis, an equilateral triangle has been adopted. The left angle represents 100 per cent sand, the right 100 per cent silt, and the top angle, 100 per cent clay. Two types of such triangles are in common use, one for the U. S. Dept. of Agriculture scale and the other for the International scale. (See Figures 2.1 and 2.2.)



SIZE LIMITS OF SOIL SEPARATES	
NAME OF SEPARATE	DIA (RANGE) MILLIMETERS
VERY COARSE SAND	2.00 1.000
COARSE SAND	1.00 0.500
MEDIUM SAND	0.50 0.250
FINE SAND	0.25 0.100
VERY FINE SAND	0.10 - 0.050
SILT	0.05 - 0.002
CLAY	BELOW 0.002

Fig 2.2 Guide for Textural Classification by the United States System for Textural Designations. *(Courtesy Soil Conservation Service)*

Textural classes are also determined from mechanical analysis data with the help of certain descriptive tables. One such table based upon U. S. Dept. of Agriculture scale is given in Table 2.3.

In the field, texture is commonly determined by the sense of feel. The soil is rubbed between thumb and fingers, preferably in the wet condition. Sand feels gritty and its particles can be easily seen with the naked eye. The silt when dry feels like flour or talcum powder and is slightly plastic when wet Clayey materials feel very plastic and exhibit stickiness when wet and are hard under dry conditions. The soil surveyor always designates the textural class in the field by this method of feeling. For accuracy, field observations are often checked against laboratory determination.

In Indonesia, the results of mechanical analysis on the Mohr ten-fraction-scale are often exhibited in the form of histograms because the main soil types are characterized by a specific particle size distribution. (See Figure 2.3.)

TABLE 2.3
PERCENTAGES OF SAND, SILT, AND CLAY IN THE PRINCIPAL TEXTURAL CLASSES** (BASED UPON U. S. DEPT. OF AGRIC. FRACTION SYSTEM)

Textural Name (Soil Class)	Ranges in per cent		
	Sand	Silt	Clay
Sand*	85–100	0–15	0–10
Loamy sand*	70–90	0–30	0–15
Sandy loam*	43–80	0–50	0–20
Loam	23–52	28–50	7–27
Silt loam	0–50	50–88	0–27
Silt	0–20	8–10	0–12
Sandy clay loam	45–80	0–28	20–35
Clay loam	20–45	15–53	27–40
Silty clay loam	0–20	40–73	27–40
Sandy clay	45–65	0–20	35–45
Silty clay	0–20	40–60	40–60
Clay	0–45	0–40	40–100

*All textual names having the word "sand" or "sandy" in them are further modified according to the fineness or coarseness of the sand. For example, a "sandy loam" soil with more than 25 per cent coarse sand will have the name "coarse sandy loam." In like manner, the word "fine" is used when the soil contains 50 per cent or more of fine sand or less than 25 per cent of coarse sand, and "very fine" if the soil contains 50 per cent or more of very fine sand.

**U. S. Dept of Agriculture—*Forest Service Handbook—Handbook on Soils*, Washington, D.C. 1960.

The texture of a soil horizon is an almost permanent character, as texture does not change over a very long period of time. The texture of the soil is one of the fundamental considerations in soil classification. Textural analysis also indicates the weathering stage to some extent. The textural class name is suggestive of many properties that have bearing on its management and productivity. Sandy soils are of open character possess good drainage and aeration, and are usually loose and friable and easy to handle in tillage operations. Clayey and silty soils, owing to their large surface area possess high adsorptive and retention capacities for moisture, gases and nutrients. They usually have fine pores, are moderate to poor in drainage and aeration, and are relatively difficult to handle for cultivation purposes.

HISTOGRAMS OF MINERAL FRACTIONS IN SURFACE SOILS IN EAST CENTRAL INDONESIA

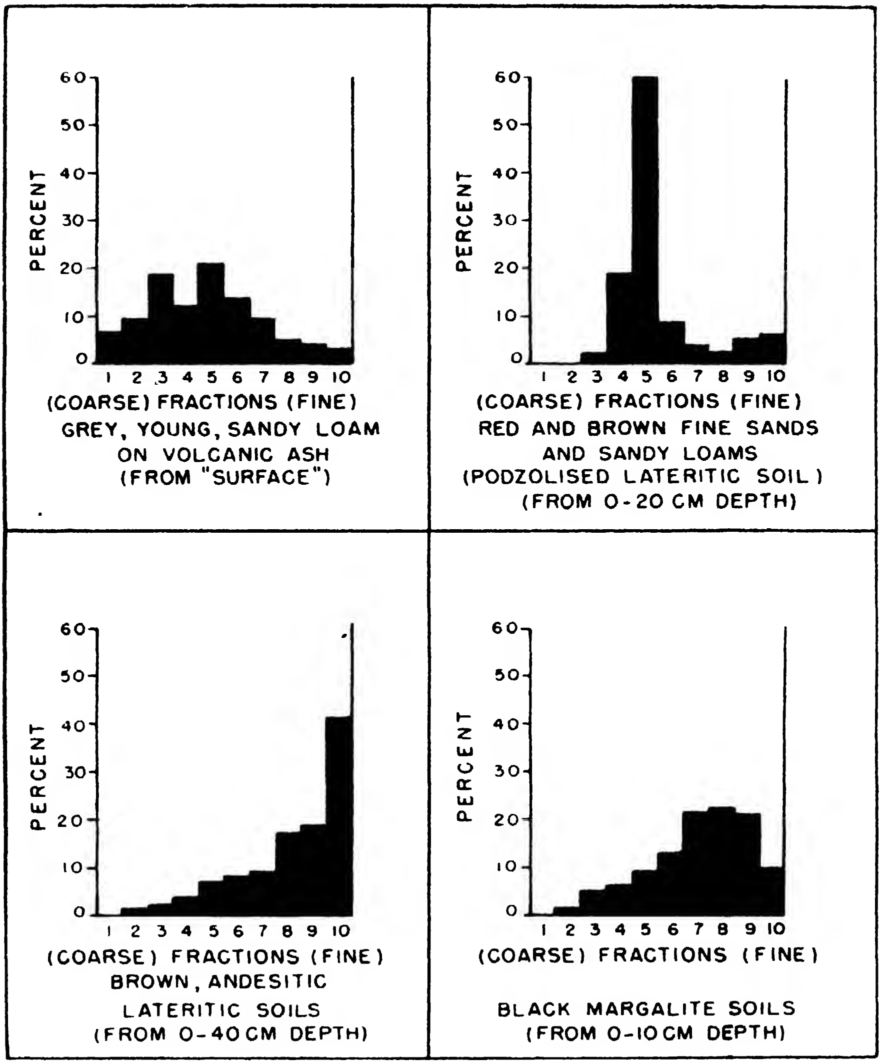


Fig 2.3 Certain soils appear to differ especially in the very fine fractions; for this reason, Mohr uses 10 fractions of soil separates instead of 4 as in the International system or 7 as in the United States system.
(See Table 2.1 for sizes of each fraction in each system) *Source*: Dames, T. W. G. *The Soil of East Central Java*. Contributions of the General Agricultural Research Station, Bogor, Indonesia, No. 141, 1955.

4. COARSE FRAGMENTS

Mineral fragments in the soil larger than 2 millimeters in diameter are not strictly a part of the soil but they greatly influence the use of the land and often cause hindrance in cultivation operations. Coarse fragments such as stones, gravels, and cobbles, are good conductors of heat, thus making the stony soils somewhat warmer. They also act as a mulch, thereby decreasing evaporation and runoff losses. Stones tend to make soils more permeable. In the classifying and mapping of soils, the names of the large fragments are attached to and precede the textural name of the soil, for example, *stony* sandy loam. The commonly accepted classification of the coarse fragments in soils is set forth in Table 2.4.

TABLE 2.4
SHAPE, KIND, SIZE AND NAME OF COARSE FRAGMENTS IN SOILS*

Shape of fragment	Kind of fragment	Size and name of fragment		
		up to 3″ in diameter	3″—10″ in diameter	more than 10″ in diameter
Rounded	Any kind	Gravelly	Cobbly	Stony
Angular	Chert	Cherty	Coarse cherty	Stony
	Other than chert	Angular gravelly	Angular cobbly	Stony
		up to 6″ in length	6″—15″ in length	more than 15″ in length
Thin, Flat	Sandstone limestone or schist	Channery	Flaggy	Stony
	Slate	Slaty	Flaggy	Stony
	Shale	Shaly	Flaggy	Stony

* *Source*: *Soil Survey Manual*, U.S. Department of Agriculture Handbook No. 18, 1951, p. 214.

Depending upon the amount of stones, (fragments more than 10″ in diameter) present in the soil, different classes of stoniness are recognized. When bed rocks are exposed on the surface of the soil as rock outcrops, the descriptive term used is rocky.

5. ORGANIC SOILS

The preceding textural names are used for designating only the mineral particles. When the surface soil is mostly organic matter, the term *muck* or *peat* is used. Muck is the name used when the organic surface, approximately a foot in depth, is so well decomposed that the plant remains are not recognizable. With less decomposition the soil is called peat.

6. SOIL STRUCTURE

The primary soil particles—sand, silt, and clay—usually occur grouped together in the form of aggregates. The arrangement of these individual particles and their aggregates into certain defined patterns is called structure. Natural aggregates are called *peds*, whereas the word *clod* is used for an artificially formed soil mass. Two other terms that are often confused with a ped are fragment and concretion. *Fragment* means a broken ped *Concretion* is formed within the soil by the precipitation of salts dissolved in the percolating waters.

Structure is best studied in the field under natural conditions and it is described under three categories :

1. Type - Shape or form and arrangement pattern of peds.
2. Class—Size of peds.
3. Grade—Degree of distinctness of peds.

7. TYPES OF STRUCTURE

There are four principal geometric forms of soil structure : (See Figure 2.4.)

1. **Plate-like :** The horizontal dimensions are much more developed than the vertical, giving a flattened, compressed, or lens-like appearance to the peds. When the units are thick, they are called *platy*, and when thin, *laminar*. (See Figure 2.5.)

2. **Prism-like :** The vertical axis is more developed than others, with flattened sides, giving a pillar-like shape. When the top of such a ped is rounded, the structure is termed as *columnar*, and when flat, *prismatic*.

3. **Block-like :** All three dimensions are about the same size and the peds are cube-like with flat or rounded faces. When the faces are flat and the edges mainly sharp angular, the structure is named as *angular blocky*. When the faces and edges are mainly rounded it is called *subangular blocky*. Earlier some of the block-like structures were called nutty or nuciform.

4. **Sphere-like Spheroidal :** Rounded or spheroidal and all axes are approximately of the same length, with curved and irregular faces. They are

usually smaller in size. The aggregates of this group are usually termed as *granular* which are relatively less porous ; when the granules are very porous, the term used is *crumby*. (See Figures 2.6, 2.7, 2.8.)

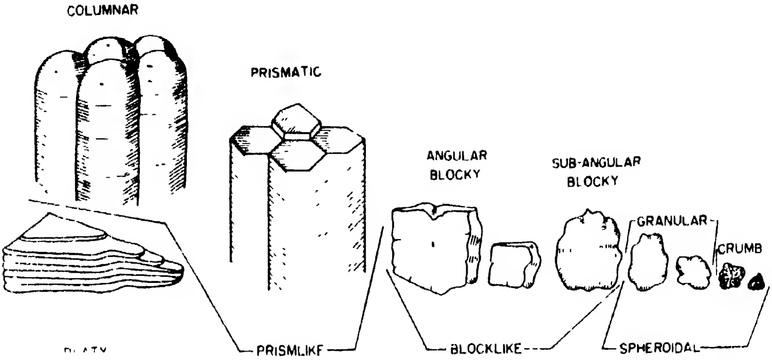


Fig. 2.4 The four main types of soil structure are : **Plate-like :** Thick-plated is called *platy*, shown here, and thin-plated is *laminar*, (not shown) **Prism-like :** *Columnar* and *Prismatic* are shown **Block-like :** *Angular Blocky* and *Subangular Blocky* are shown. **Sphere-like :** *Spheroidal Granular* and *Crumb* are shown

8. CLASSES OF STRUCTURE

Each primary structural type of soil is differentiated into five size-classes depending upon the size of the individual peds. The terms commonly used

Fig. 2.5 Plate-like structure may be seen on the surface of the soil to the *right*, apparently caused by standing water and crust formation.
Block-like structure exists on the left where the soil has been recently ploughed.

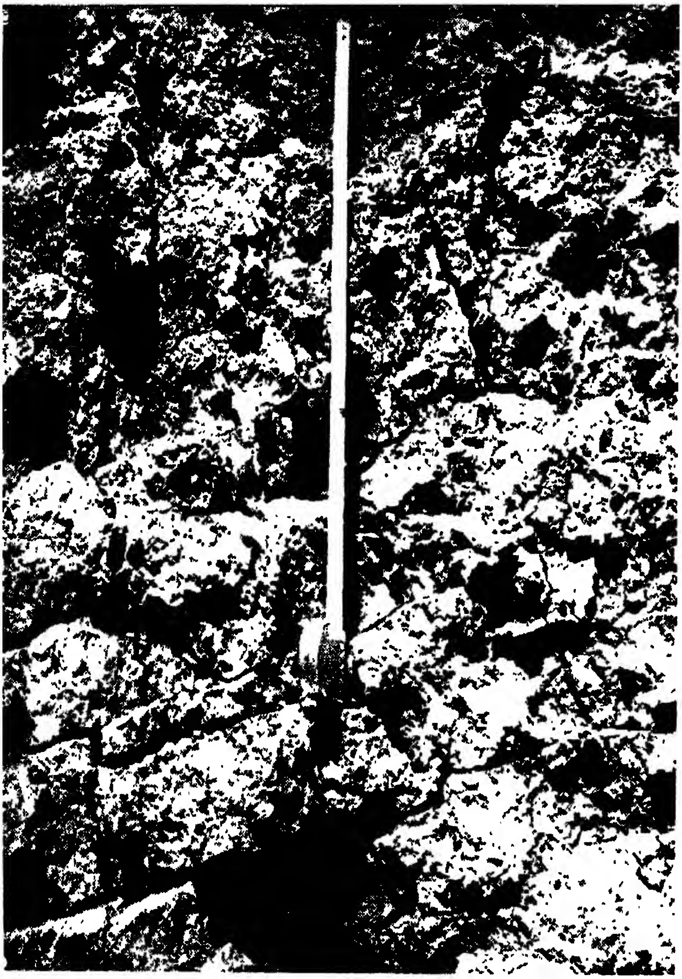


Fig. 2.6 The top portion of the photograph shows moderately to strongly developed subangular and angular blocky structures which grade into (bottom) the following designation . Type of Structure · Block-like (Angular) Class of Structure Very Coarse Grade of Structure · Strong , which is called *strong very coarse angular blocky*
(Note : If the peds at the bottom had their long axis upright, the name would be *prismatic*)

for the size classes are :

1. Very fine or very thin
2. Fine or thin
3. Medium
4. Coarse or thick
5. Very coarse or very thick.

The terms thin and thick are used for platy types, while the terms fine and coarse are used for other structural types.

9. GRADES OF STRUCTURE

Grade indicates the degree of distinctness of the individual peds. It is determined by noting the stability of the aggregates and the ease with which they separate from other peds. Grade of structure is influenced by the

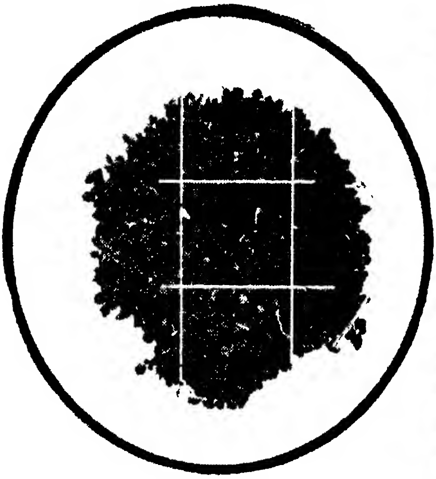


Fig. 2.7 Examples of sphere-like soil structure :

Photo	*Grade*	*Class*	*Type*	*Structural Name*
Left	*strong*	*fine*	*granular*	*strong fine granular*
Right	*moderate*	*very coarse*	*granular*	*moderate very coarse granular*

The square in the LEFT photo is one inch. *(Courtesy John Deere and Co).*

Fig. 2.8 *Strong coarse angular blocky* structure in clayey soils Under moist conditions (lower right) the structure is *structureless*. Upon drying the clay shrinks and the structure shows up more distinctly and can be easily recognised in the field (Scale is in inches.)

moisture content of the soil. Under moist conditions the soil structure is usually not very distinct. With exposure and drying, the structure becomes much stronger. Four terms commonly used to describe the grade of soil structure are :

1. **Structureless :** There are no noticeable peds, such as conditions exhibited by loose sand or a cement-like condition of some clay soils. If the appearance is coherent as in compact clay, the term used is *massive*, if non-coherent as in loose sand, *single grain*.

2. **Weak :** Indistinct formation of peds which are barely durable.

3. **Moderate :** Moderately well-developed peds which are fairly durable and distinct.

4. **Strong :** Very well formed peds which are quite durable and distinct. For naming a soil structure the sequence followed is grade, class, and type ; for example, strong coarse angular blocky. Often compound structures are met with in the soil under natural conditions. On drying or when gently disturbed, they break into individual small structural peds that constitute the compound structure. For example, large prismatic or columnar types may break into medium blocky structure. Considerable care and experience are needed for proper and accurate designation of the soil structure. (See Figures 2.9, 2.10.)

Fig. 2.9 *Strong Very Coarse Subangular Blocky* structure which, upon drying, is changing into *Strong Medium Subangular Blocky* structure.

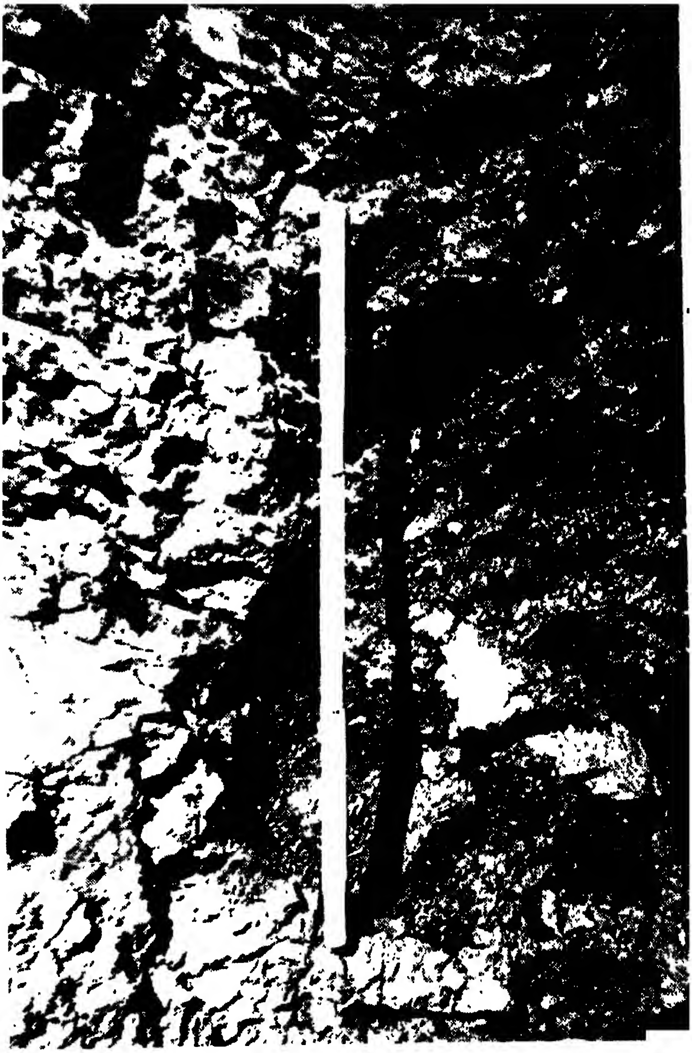


Fig. 2.10 The typical structure of sub-soil horizons in deep clayey black soils of India. It consists of *moderate* to *strong coarse platy* structure lying in slants or inclined planes, sometimes developing into convex lens shapes (similar to lentil seed). The *ped* surfaces are usually shiny in appearance (Scale is in inches)

10. STRUCTURE FORMATION

The mechanism of structure formation is quite complex. However, for the formation of aggregates the soil particles should coagulate and flocculate and should be held together or bound together into clusters by some binding, cementing, or gluing material, such as plant roots, lime, oxides of iron and alumina, or colloidal organic matter. Polysaccharides and polyuronides which are synthesized by microorganisms and secreted, for example, by earthworms, are very effective binding materials. Many salts are responsible for causing flocculation of the colloids.

Parent material, climate, and some of the soil-forming processes also affect aggregation. In soils developed from shales, platy structure may be inherited. Blocky and prismatic types of structures are mostly associated

with subsoil horizons. Presence of columnar and prismatic structure in subsoil horizons is sometimes associated with the formation of solonetz (alkali) soils. The special vesicular or honeycomb structure is a typical characteristic of laterization. In black soils of India, characteristic structure in subsoil horizons called "lentil" (resembling lentil seed) has been described. When well developed it assumes a shape like a convex lens. Such structures usually lie in an inclined plane of about 30 degrees, giving a slanting appearance. The structure is similar to the coarse platy type. (See Figure 2.10.)

The agencies which greatly influence structure formation are alternate wetting and drying, alternate freezing and thawing, and those associated with microbial activity and plant root action.

11. IMPORTANCE OF SOIL STRUCTURE

Structure is very important in plant growth relationships, as it chiefly influences the amount and nature of porosity and regulates the moisture air regime in the soil. Platy structure normally hinders free drainage. The best structures for favourable physical properties of soil are crumby and granular. (See Figure 2.7). It is the *stability* of the aggregates (power of resistance against disintegrating forces of water and physical action) which is most vital in structural behaviour of soil. Some structures are mechanically stable and strong but when they absorb moisture and are wet, they become soft and lose their shape and size. Soils high in water-stable aggregates are more permeable to water and air. When stable aggregates are less, the soils tend to puddle.

Structure is one of the soil properties which is easily liable to changes under different management practices such as ploughing, draining, liming, fertilising, and manuring. Addition of organic matter and its proper decomposition are important for building up and maintenance of soil structure. Grasses are most effective in promoting granulation.

In most parts of Tropical Asia, rice is grown by puddling the soil when it has shallow standing water on it, so that the rice plants may be easily pushed into the soil in the process of planting. The puddling destroys all clods and peds, resulting in a structureless mass that makes it very difficult to prepare a good tilth for the seed bed for the next crop. (See Figure 2.11.)

12. DENSITY OF SOIL

Density represents weight per unit volume of a substance. Soil density is expressed in two well accepted concepts—particle density and bulk density.

Fig. 2.11 Puddling a soil in preparation for planting rice (above) destroys all peds and clods which upon drying, makes a structureless mass When an upland crop such as wheat follows rice, the clods often must be broken by beating them with a stick (below).

Particle Density : The weight per unit volume of the solid portion of soil is called particle density. It depends upon the accumulative densities of the individual inorganic and organic constituents of the soil. Particle density of predominantly mineral soils varies from 2.6 to 2.75 gm/cc, whereas that of organic matter varies from 1.2 to 1.7. A generally accepted figure of particle density for the normal soils is 2.65 grams per cubic centimeter or 165 pounds per cubic foot. The particle density is higher if large amounts of heavy minerals such as magnetite, limonite, hematite, and

zircon, are present in the soil. With increase in organic matter of the soil, the particle density decreases. Particle density is sometimes also termed as *true density*. When particle density is divided by density of water, a relative weight number is obtained called *specific gravity*. The figures for particle density and specific gravity of soil are almost identical.

Bulk Density : The oven dry weight of a unit volume of soil inclusive of pore spaces and expressed as grams per cubic centimeter or pounds per cubic foot is called *bulk density*. Bulk density of soil divided by density of water is known as *volume weight* or *apparent specific gravity*. Bulk density is estimated by determining the oven dry weight of an undisturbed core of soil of known volume. Different types of cylinders are used to collect the soil core in its most natural condition. The bulk density of a soil is always smaller than its particle density. The bulk density of sand is about 1.7 grams per cubic centimeter, whereas that of organic matter like peat is about 0.5. Bulk density normally decreases as mineral soils become finer in texture.

The bulk density varies indirectly with the total pore space present in the soil and gives a good estimate of the porosity of soil. Bulk density is of greater importance than particle density in understanding the physical behaviour of soils. Generally, soils with low bulk densities have favourable physical conditions, whereas those with high bulk densities exhibit poor physical conditions.

Bulk density helps to determine the weight of the soils. The weight of one cubic foot of sandy, sandy loam, or loamy soils varies from 80 to 110 pounds per cubic foot, and that of silt loam, clay loam, and clay soil ranges from 70 to 100 pounds.

13. POROSITY OF SOIL

Porosity refers to that percentage of soil volume which is occupied by interstitial spaces or pore spaces. It is calculated as follows :

$$\text{Percentage pore space} = 100-\left(\frac{\text{Bulk density}}{\text{Particle density}}\right)\times 100$$

For example, a soil having bulk density of 1.5 and particle density of 2.65 has the following percentage pore space : $100-\left(\frac{1.5}{2.65}\right)\times 100=43.40\%$

Porosity varies with the texture of soil, shape of individual particles,

soil structure, amount of organic matter, and the compactness. In sandy soils, although the pores are quite large, yet the total pore space is small. In fine-textured soils, there is possibility of more granulation, and total pore space is high because of spaces between individual particles and within granules. From sandy soils to clay soils the pore space varies from 32 to 50 per cent. In the presence of organic matter, it further increases and may rise up to 60 per cent in grassland soils. Clayey soils show wider variations in pore space than sandy soils.

Porosity of soil indicates total pore space and not the size and form of individual pores. Depending upon the size of pores, macro-and micro-pores are recognized, but determination of their individual amounts or proportion is quite difficult. If it could be estimated, it could greatly help to judge the moisture movement within the soil. Macro-pores (non-capillary) allow ready movement of air and water and do not hold much water under normal conditions. Micro-pores (capillary) can hold more water but the movement of air and water is restricted to some extent. Size of individual pores, rather than total pore space in a soil is more significant in its plant growth relationship. For ideal conditions of aeration, permeability, and water retention, a soil should have about an equal amount of macro-and micro-pores.

Porosity of a soil is easily changed. Any operation that reduces aggregation and decreases the amount of organic matter in the soil, decreases pore space. Porosity normally decreases with depth in the soil

14. SOIL CONSISTENCE

Soil consistence represents, at varying moisture conditions, the degree and kind of cohesion and adhesion of soil material or resistance offered to the forces tending to deform or rupture the soil mass. Cohesion refers to the attraction of substances of like characteristics such as that of one water molecule for another. Adhesion is the attraction of unlike materials where the substances are more or less firmly attached together by their adjacent surfaces.

Consistence of soil depends on the texture, nature and amount of inorganic and organic colloids, structure, and especially the moisture content of soil. With decreasing moisture content, in general, the soils lose their stickiness and plasticity and become friable and soft, and finally when dry become hard and coherent. The terms commonly used to describe soil

consistence at different moisture contents are :

Consistence when wet. (At about field capacity moisture content).

Stickiness	The quality of adhesion to other objects. Terms used are non-sticky, slightly sticky, sticky, very sticky.
Plasticity	The capacity to form moulds. The terms used are nonplastic, slightly plastic, plastic, and very plastic.

Consistence when moist. (Slightly wet, about in between air-dry and field capacity moisture content). It is characterized by friability which indicates ease of crumbling of soils. The terms used are loose, very friable, friable, firm, very firm, and extremely firm.

Consistence when dry. (Air-dry conditions). It is characterized by rigidity and hardness. The terms used are loose, soft, slightly hard, hard, very hard, and extremely hard.

Cementation. It refers to brittle, hard consistence caused by some cementing agents such as calcium cabonate, silica, or oxides or salts of iron and aluminum. The terms used are weakly cemented, strongly cemented, and indurated.

Plasticity. This refers to the ability of soil materials under wet conditions to change shape continuously under the influence of an applied force and to retain the impressed shape on release of the force and even after drying.

Amount and nature of colloidal material greatly influence the plasticity. Siliceous clay fractions exhibit strong plasticity as compared to those high in sesquioxides. It is due probably to plate-like nature of the clay particles. Montmorillonite clays are more plastic than kaolinite clays. Plasticity of soil normally increases with increase in its clay content.

Different soils are characterized by a specific *plastic number* which is the difference between moisture contents of a soil at its upper and lower plastic limit. *Upper plastic limit* represents the moisture content of soil at a point where the soil-water mass just flows under an applied force and fails to retain its shape. *Lower plastic limit* refers to the moisture content of a soil at a point where its consistence changes from plastic to friable and the soil-water mass is unable to change shape continuously under the influence of an applied force; and ultimately the mass breaks into fragments.

15. SHRINKAGE AND SWELLING

Contraction and expansion in volume of soil with changing moisture content are more marked in clayey soils. Shrinkage on drying in fine clayey

soils and highly organic soils produces prominent cracks which may extend several feet deep. With increase in moisture, the water is imbibed, especially between the lattice structure of clay particles and leads to swelling. Shrinkage and swelling are more prominent in montmorillonite clays which have an expanding lattice structure than in kaolinites with non-expanding lattice structure. (See Figure 2.12.)

The swelling and shrinkage characteristics of soils play a significant role in formation of structure, such as prismatic, columnar, and blocky types. The "*gilgai*" microrelief, commonly found in dark clay soils (grumusols) is perhaps also due to their high coefficients of expansion and contraction. (See also Chapter 5.)

16. SOIL COLOUR

The colour of the soil varies widely amongst various kinds of soils as well as within different horizons of a soil profile. It is an easily observable characteristic and is an important criterion in description and classification of soils. Many soil groups have been named after prominent soil colours such as Black Soils, Red-Yellow Latosols, Grey Hydromorphic Soils.

Colour of a soil may be inherited from its parent material ; for example, red soils developed from red sandstone, and is referred to as *lithochromic*. Often the soil colour is a result of soil-forming processes and is termed as *acquired* or *genetic* colour ; for example, red soils developed from granite-gneiss or schist.

The variations in soil colour are due mainly to the organic matter content which generally imparts black to dark grey tinges; iron compounds which are responsible for red, brown, and yellow tinges; and silica, lime and other salts which give light, white, and grey tinges. The surface horizon of soil is commonly darkest, due mainly to the presence of organic matter. Red colour is associated with unhydrated ferric oxides, whereas yellow colour indicates some degree of hydration. Red colour is generally suggestive of relatively old and intensely weathered, well-drained soils such as lateritic soils in tropics. Brown is the most common soil colour and is due to a mixture of the organic matter and iron oxides. Some of the bluish and greenish colours are due to the presence of ferrous compounds created by reducing conditions in imperfectly drained soils such as marsh and high-water-table bottom lands. Colour variegation or mottling in soils indicates alternating oxidizing and reducing conditions due mainly to a fluctuating water table.

It may thus be observed that soil colour is indirectly indicative of many other properties of soil. Directly the soil colour influences soil temperature

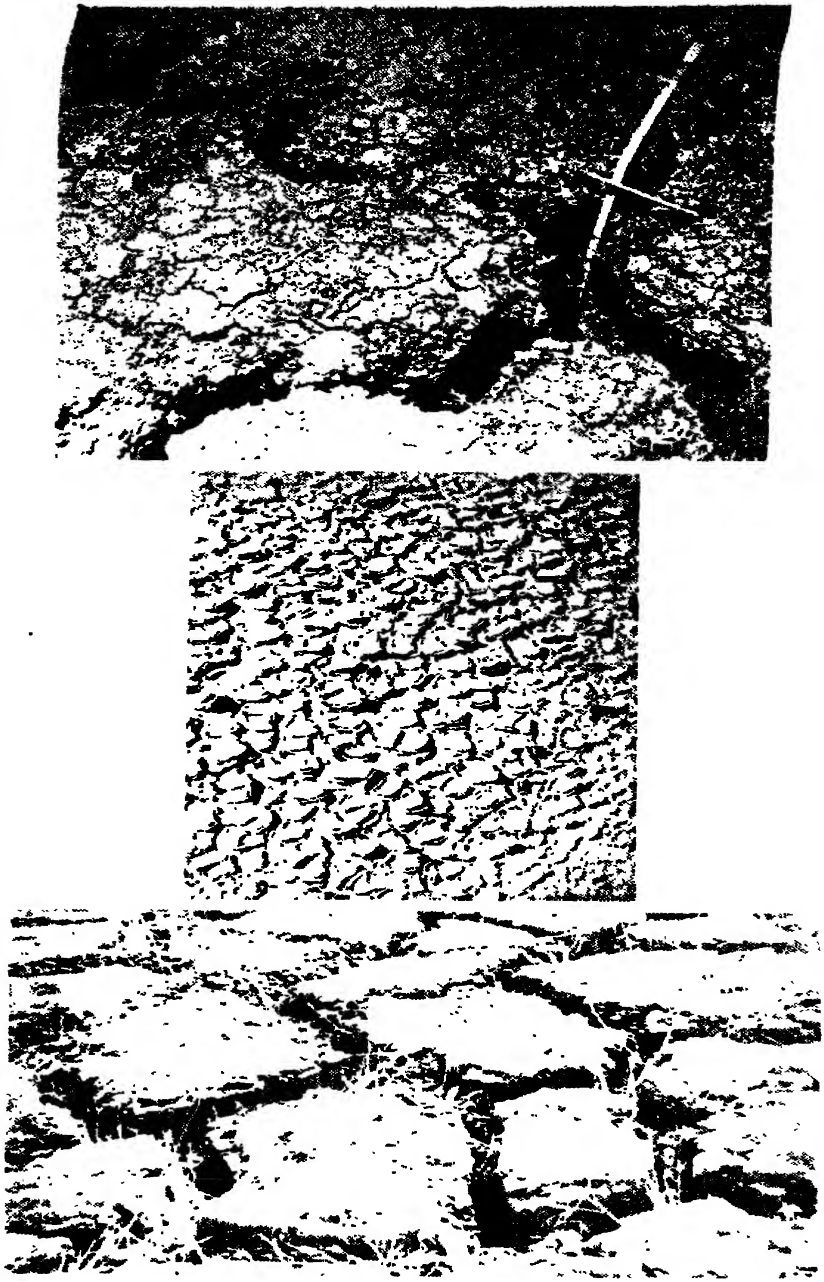


Fig. 2.12 Top. The typical cracking of highly clayey black soils. This cracking is due mainly to high coefficients of expansion and contraction Due to this cracking property black soils are sometimes termed as "self-ploughing" or "self-muching". The maximum size of these cracks is about 4 inches wide and 4 feet deep. **Centre.** Shrinkage of soil that has been washed into a borrow pit **Bottom.** Another type of soil shrinkage in a wheat field, with structural units about one foot square. (*All photographs were taken in India.*)

to some extent. The dark coloured soils absorb more heat than light coloured soils. The work at Poona* (Maharashtra, India) showed that black cotton soil absorbed about 86 per cent of total radiation against 40 per cent by the grey alluvial soils.

The soil colours are best determined by comparison with standard colour charts. The Munsell** soil colour chart is commonly used for this purpose. The colour of the soil is a result of the light reflected from the soil, and it depends upon the combination of three simple variables of colour; namely, hue, value, and chroma. *Hue* is the dominant spectral colour. *Value* is the brilliance or total quantity of light. *Chroma* is the relative purity or saturation of the dominant spectral colour. The Munsell colour notations are systematic numerical and letter designations of each of these three variables. For example, the numerical notation 2.5 YR 5/6 constitutes 2.5 YR as hue, 5 as value and 6 as chroma. The equivalent soil colour name for this Munsell notation is "red".

The colour of soil when wet is normally darker than when it is dry. The colours are more vivid and strongly contrasted in colour under wet conditions. Soil high in colloidal materials comparatively show more marked contrast in colour under dry and wet conditions. The general practice is to describe the soil colour under both dry and moist conditions.

17. SOIL TEMPERATURE

Plant growth as well as chemical and biological activities in the soil are greatly influenced by the soil temperature. Plant growth slackens at about 40° F temperature. Nitrification processes through microorganism are at their maximum between 80-90°F temperatures. Soil temperature also regulates soil-air movement to some extent.

The heat radiation from the sun is the primary source of soil heat. The soil temperature is primarily dependent on the heat that soil absorbs in relation to the losses through radiation and evaporation of soil moisture. The amount of heat that enters the soil is controlled by climate, colour of soil, altitude and aspect of the land, and the vegetative cover present on the soil.

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*Ramdas, L.A. and Dravid, R.K., *Soil Temperatures in Relation to other Factors Controlling the Disposal of Solar Radiation at The Earth's Surface*. Proc. Nat. Inst. Sci. India, 2:131-143, 1936.

***Munsell Soil Color Charts*. Munsell Color Company Inc. Baltimore 2, Maryland, USA.

Generally, the mean annual temperature of the soil is higher than that of its surrounding atmosphere. At Djakarta* (Indonesia) the mean annual temperature of the air was 78°F against 85°F at a soil depth of 44 inches. The temperature of the surface soil usually shows much more fluctuation. Below a certain depth, the temperature of the soil is not affected by seasonal and diurnal changes and remains almost constant. At Poona** (Maharashtra, India), on black cotton soils, temperatures of surface soil as high as 165°F have been recorded. Even higher temperatures are possible in certain Tropical Asian regions.

Soil moisture is the most vital controlling factor in soil temperature. *Specific heat* is the amount of heat required to raise the temperature of one gram of a substance by 1°C. The specific heat of dry soil is only about one-fifth that of water. Hence, moist soils are cooler due to their high specific heat and also due to the heat energy spent in evaporation of soil moisture. Draining a soil, therefore, helps to make the soil warmer. Good structured soils also warm up sooner than those with poor structure because they become dry more quickly. Man can influence the soil temperature through drainage management of soils and by changes in the vegetative cover of the soil.

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CHAPTER THREE

SOIL WATER

"*Though you allow shade, allow no water to stand.*"

ANCIENT TAMIL PROVERB

Water is essential for all forms of life. In plant growth, water not only forms a major part of the plant itself, but it is also essential for the process of photosynthesis, acts as a solvent and nutrient carrier from soil to the plant and within the plant, and also maintains the turgidity of the plant. Water influences, in a prime way, the process of weathering of rocks and genesis of soil. The different kinds of soils formed depend to a great extent on the movement behaviour of water in the soil. Saline soils result primarily due to excessive upward movement of water in the soil. Water is also responsible for soil erosion. In fact, the soil water is a great regulator of physical, chemical, and biological activities in the soil.

Water plays a very significant role in soil-plant growth relationships. Although plants absorb some water directly from rain and dew, most of the water used by plants comes from water held by the soil. Often an excess or deficit of water in the soil is a limiting factor in plant growth and proper soil and water management is foremost in profitable agriculture.

The main sources of soil water are through precipitation and irrigation ; whereas it is lost from the soil mainly through percolation to ground water and stream flow, and evaporation and transpiration to the atmosphere. The water is also lost through surface runoff with the accompanying hazards of soil erosion. Although runoff loss of water occurs without becoming a part of soil water, yet any reduction in the runoff loss through proper soil and water conservation measures helps augmentation of soil-water resource which is of special significance in water scarcity areas. Soil, therefore, serves as a regulated reservoir for water.

To make maximum use of soil water it is desirable to know how it moves into and through the soil, how it is classified and measured, and what can be done to reduce losses of water due to percolation and evapotranspiration. Percolation also causes leaching losses of nutrients. The better understanding of soil water movement and retention characteristics is of particular importance in cultivation, irrigation, drainage, soil and water conservation practices, and watershed management.

The movement and retention of water in the soil is primarily affected by soil characteristics such as texture, structure, nature and amount of inorganic and organic colloidal materials, kind and quantity of exchangeable cations, and size and total volume of pore space.

I. INFILTRATION

Infiltration refers to the downward entry or movement of water into the soil surface. By contrast *percolation* is the movement of water *through* a column of soil generally under saturated or near-saturated conditions. *Permeability* indicates the relative ease of movement of water *within* the soil.

It is obvious, therefore, that a soil should be in such physical condition as to provide channels down through which water may move as rapidly as it is received on the surface as rainfall or irrigation. Water which cannot move into the soil moves off over the surface, often carrying soil with it. The result is a reduced productivity due to the loss of fertile topsoil and less water for plant growth.

Factors Affecting Infiltration : Infiltration being a surface characteristic, it is primarily influenced by the conditions of the surface of the soil. A compact surface permits less infiltration. The impact of rainfall which often causes sealing and closing of pores, especially in easily dispersable soils, reduces infiltration. Rainfall impact directly affects infiltration and does not affect percolation. Soil surfaces with vegetative cover have more infiltration rate than bare soils. Warm soils absorb more water than cold ones. In clayey soils, cracking caused by drying also increases infiltration in the initial stages until the soil again swells and decreases infiltration.

Coarse surface textures, a large number of water-stable aggregates, a larger amount of organic matter in the surface soil, and a greater number of macropores all help to increase infiltration. The amount of water initially present in the soil also affects infiltration. After the soil becomes saturated, further infiltration rate depends on the percolation rate. In general, infiltration rate is comparatively lower in wet soils than in moist or dry soils.

The depth of soil to a hardpan, bed rock, or other impervious layer is also a factor in infiltration. Shallow soils permit less water to enter into the soil than do deep soils.

Infiltration is a dynamic and quite variable character of the soil and can be fairly well controlled by management practices. Cultivation practices that loosen the surface soil make it more receptive for infiltration, whereas those causing compactness reduce infiltration. Coarse organic matter mulches on the soil are especially effective in increasing the movement of water into the soil.

Infiltration Rates : Infiltration rates may be classified as follows :

1. **Very Slow :** Soils with infiltration rates of less than 0.1 inch per hour are classified as very low. In this group are the soils that are very high in percentage of clay. (See Figure 3.1.)
2. **Slow :** Infiltration rates of 0.1—0.5 inch per hour are considered low. This group includes soils high in clay, soils low in organic matter, or shallow soils.
3. **Moderate :** Rates of infiltration of 0.5—1.0 inch per hour are classified as medium. Most soils in this group are sandy loams and silt loams.

Fig. 3.1 The rate of infiltration in this very fine textured clayey black soil is classified as very low to low. *(Deep black soil profile from Deccan Trap Area of India.)*

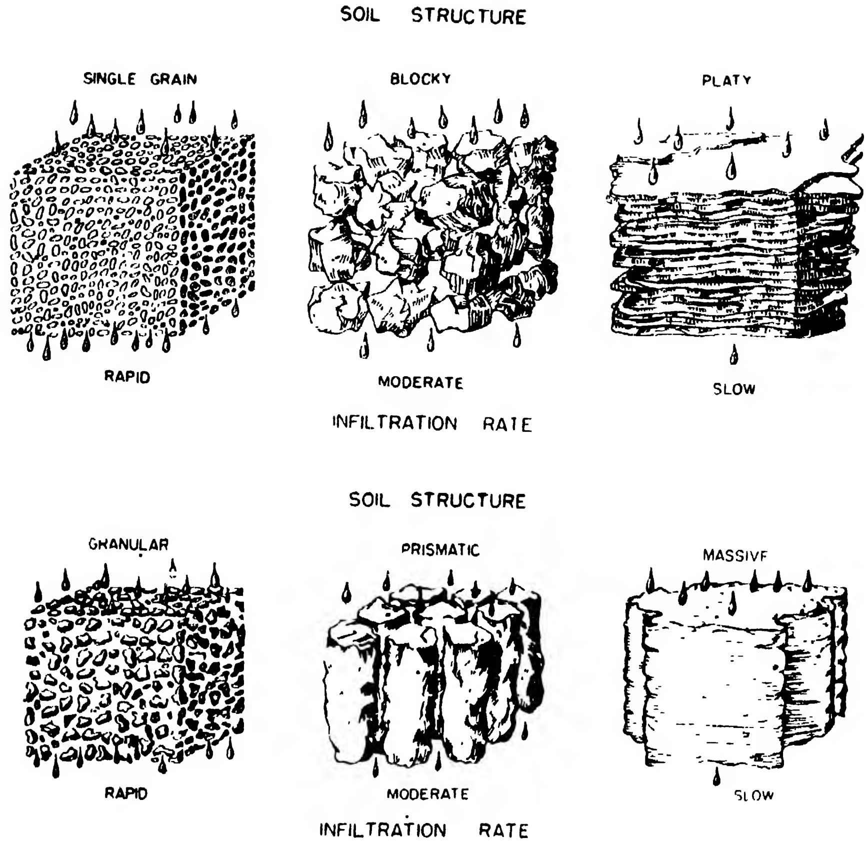

Fig. 3.2 The general relationship between soil structure and infiltration rate of water in soils. (*Source : United States Information Bulletin No 199, 1959*).

4. **Rapid :** High rates include soils with greater than 1.0 inch per hour of infiltration. Deep sands, and deep, well-aggregated silt loams are in this group. (See Figure 3.2.)

2. PERMEABILITY

The characteristics that determine how fast air and water move through the soil describe what is known as *permeability*. The term *hydraulic conductivity* is also used which refers to the readiness with which a soil conducts or transmits fluids through it.

The permeability is basically dependent on the pore-size distribution in the soil. The larger the number of macro-pores (non-capillary pores) the

greater is the permeabitity. The pore-size distribution is greatly determined by the extent of aggregation in the soil. The larger the aggregates, the greater is the amount of non-capillary pores, as indicated in Table 3.1. With increase in aggregate size, from less than 0.5 mm. to 5 mm., non-capillary porosity increases from 2.7 to 38.7 per cent which is about a 14-fold increase.

TABLE 3.1
RELATIONSHIP OF SOIL POROSITY TO THE SIZE OF AGGREGATES*

Size of aggregates (diameter in mm.)	Porosity in per cent		
	Total porosity	Non-capillary porosity	Capillary porosity
Less than 0.5	47.5	2.7	44.8
0.5 to 1.0	50.0	24.5	25.5
1.0 to 2.0	54.7	29.6	25.1
2.0 to 3.0	59.6	35.1	24.5
3.0 to 5.0	62.6	38.7	23.9

*Source: Baver, L. D., *Soil Physics*. John Wiley & Sons, Inc. New York. Chapman & Hall Ltd., London, 1959.

The permeability of soil usually decreases with depth, as the subsoil layers are more compact and compactness particularly reduces macro-pores. There is less of organic matter in subsoil horizons and hence lack of good aggregation. Whereas organic matter content is an important factor affecting permeability of surface horizons, the colloidal properties of clay become more dominant in determining permeability at lower depths.

Texture and structure of a soil are often studied in the field for qualitative assessment of permeability. The permeability of a soil is limited by the least permeable horizon in the soil profile, such as by ploughpans, natural claypans, hardpans, or other obstructing layers. Permeability increases with coarseness of soil texture. Textures finer than sandy loam are not directly related to permeability. Normally permeability decreases with increasing fine texture, but the extent of aggregation in fine-textured soils may override the effects of texture.

Concentration and composition of salts dissolved in irrigation water also affect permeability of the soil. If water is high in sodium content, it would cause ready dispersion of soil and thus reduce permeability. In case total salt concentration is high enough to prevent dispersion, the permeability may not be affected.

Like infiltration, the permeability can also be controlled to a large extent by suitable management practices. Continuous tillage reduces permeability, while the growth of deep-rooted grasses, legumes, and trees

increases permeability. Maintenance of good aggregation is very important in maintaining the productivity of the soil.

Suggested permeability classes for saturated soils are as follows :

	Class	*Inches per hour*
1.	Very slow	Less than 0.05
2.	Slow	0.05— 0.20
3.	Moderately slow	0.20— 0.80
4.	Moderate	0.80— 2.50
5.	Moderately rapid	2.50— 5.00
6.	Rapid	5.00—10.00
7.	Very rapid	more than 10.00

Permeability of a soil varies with its moisture status and usually decreases as the soil becomes drier. The air that is introduced into a soil on drying often acts as a non-conducting part of the soil system to reduce permeability.

3. PERCOLATION

The movement of water through a column of soil is called *percolation*. Percolation studies are important for at least two reasons. Percolating waters are the only source of recharge of ground water which can again be profitably used through springs and wells for irrigation and other purposes. Also, percolating waters carry plant nutrients down and often out of reach of plant roots.

Percolation is primarily dependent on the climate, especially rainfall and evaporation. A balance in favour of more rainfall than evaporation would cause an appreciable amount of percolation. In dry regions, percolation is almost negligible. In Tropical Asian countries where rainfall is in excess of 40 inches and is mainly received through a few rainy months of monsoonic season, percolation is usually high. Fluctuating ground-water tables in Tropical Asian countries are common ; being high during the monsoon rainy season and low during periods of no rain.

Percolation is also affected by the nature of soil. Sandy soils permit greater percolation and clay soils will permit less water to move through them. The growing crops and other vegetation on the soil considerably reduce the percolation losses, as a good amount of water is utilized in plant growth. (See Figure 3.2).

Leaching Losses of Nutrients : Percolation losses of water are not harmful but the nutrients that are leached along with the percolating water

are of serious consideration. Actual leaching losses of plant nutrients from a New York soil (U.S.A.) are in the relative order of :

$$Ca > Mg > S > K > N > P$$

Only a trace of phosphorus is lost by leaching while the losses of calcium are the greatest of all the nutrients shown. It is also seen that bare soil loses more nutrients by leaching than when the soil is under a crop.

Although no particular data on nutrient losses are available from Tropical Asian countries, the trends shown by results in U.S.A. should serve as a fairly good guide for nutrient losses by leaching.

4. FORCES CAUSING WATER MOVEMENT

The movement of water in the soil through infiltration and percolation is caused mainly by gravity and capillary tension. The force of gravity, although acting constantly, is effective in downward and to some extent in lateral movement of soil water, only when the soil is in a saturated condition. Under moist and semidry conditions, the capillary tension is more pronounced in movement of water from areas of low tension to those of higher tension.

The other two forces which cause some water movement in the soil are vapour pressure and osmotic pressure, but are not as significant as forces of gravity and capillary tension. Osmotic pressure is of some importance in soils which have excessive salts. Vapour pressure causes some diffusion of water vapour mainly from moist areas to dry ones and from warmer to cooler areas.

5. WATER RETENTION IN SOIL

The soils hold water due to their colloidal properties and aggregation qualities. The water is held on the surface of the colloidal and other particles and in the pores. The earlier concept about water retention in the soil was the capillary tube hypothesis in which the soil was considered to be consisting of a large number of capillaries of varying sizes. The forces responsible for retention of water in the soil after the drainage has stopped are due to surface tension and surface attraction and are called surface moisture tension. This refers to the energy concept in moisture retention relationships. The force with which water is held is also termed as **suction.**

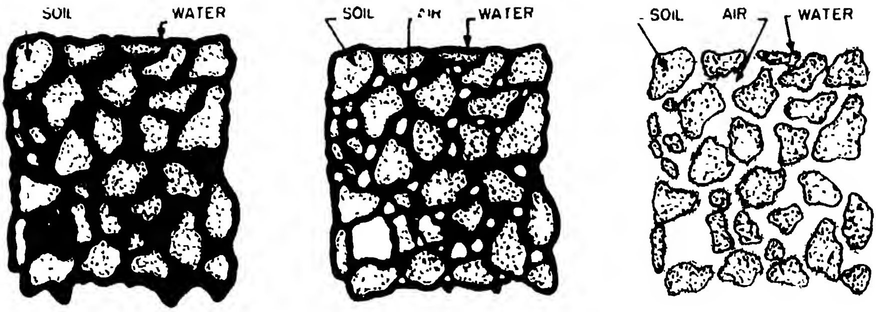

Fig. 3.3 Diagrammatic scheme for showing the soil at saturation, field capacity, and wilting point.

These forces are measured and expressed in different ways as follows :

(a) The force equal to the weight of a column of water one square centimeter in cross-section, recorded in centimeters of height. The centimeter height of the column is often expressed as a logarithm and written as pF where p indicates the logarithmic value and F as free energy, e.g., pF 3 is equal to 1,000 centimeters of a water column height (logarithm of 1,000=3).

(b) Since force per unit area is pressure, the soil moisture tension is commonly expressed in *atmospheres.* (One atmosphere at sea level is approximately 15 pounds per square inch). One atmosphere of tension means that the force holding the water is equal to about 15 pounds per square inch or to 1,032 centimeters of water column height and is roughly equivalent to pF of 3.

Moisture-Tension Curves : Soils differ considerably in their capacity to retain water. Fine-textured soils retain much more water than coarse textured soils. The greater the aggregation, the larger is the amount of water held. Moisture tension curves relating tension with moisture content of the soil can be prepared for particular soils. The moisture that is retained at different tensions increases with an increase in the amount of fine particles.

Moisture tension curves are sometimes used to determine the pore-size distribution in the soils because water from large pores moves out at much lower tension than from smaller pores. These curves also help to provide information about the water release or water supplying properties of the soil.

6. SOIL WATER CLASSIFICATION

Soil water has been classified in many ways and by many people. One of the earlier classifications divided soil water into hygroscopic, capillary, and gravitational water. One of the most modern and meaningful classifications is based upon the forces with which water is held by the soil. In this way soil water is more directly related to the force which plant roots exert in absorbing water.

The total of all the forces which the plant must overcome to take up water from soil is called *soil moisture stress.* This stress represents mostly the combined forces of soil moisture tension and osmotic tension in the soil due to dissolved salts. Where dissolved salts are negligible, the soil moisture stress is equal to soil moisture tension.

When plants permanently wilt for lack of water, it means that the pull of the roots is not great enough to get sufficient water in time to prevent wilting. This amount of water in the soil is held with a force of 15 atmospheres and is called *wilting percentage.* Plants cannot grow normally in a soil wetter than the field capacity. The moisture at the field capacity is held with a force of one-third atmosphere.

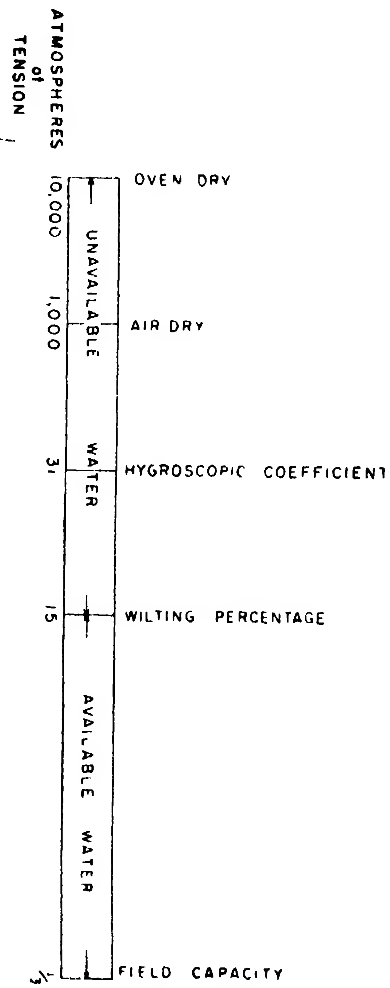

Fig. 3.4 The soil moisture constants in terms of atmospheres of tension

7. SOIL MOISTURE CONSTANTS

The soil moisture constants are shown diagrammatically in Figure 3.3, and in terms of atmospheres of tension in in Figure 3.4.

Oven Dry Weight is the basis for all soil-moisture calculations. The equilibrium tension of the moisture at oven dryness is 10,000 atmospheres. In its actual determination in soils, oven dryness is determined by placing the soil in an oven at 105°C until it loses no more water.

Air Dry Weight is a somewhat variable term, mainly because the moisture in the air fluctuates. Under average conditions, moisture at air dryness is held with a force of 1,000 atmospheres. This water is not available to plants.

Hygroscopic Coefficient is determined by placing an air-dry soil in a nearly saturated atmosphere at 25°C until it absorbs no more water. This tension is equal to a force of 31 atmospheres. Water at this tension is not available to plants but may be available to certain bacteria. Hygroscopic coefficient varies with colloidal content of soil. Soils rich in clay and organic matter and those rich in sesquioxides such as laterites show high hygroscopic coefficients.

Wilting Percentage water is held with a force of 15 atmospheres (220.5 pounds per square inch). It is almost a marvel of nature that plant roots can pull water with such a force. Terms like *permanent wilting point* or *wilting coefficient* are also in use and indicate the percentage moisture content of a soil at which a plant wilts and is unable to recover. The values for wilting percentage are markedly increased by the colloidal content of the soil.

Field Capacity is the capacity of the soil to retain water against the downward pull of the force of gravity. The field capacity of a soil with good drainage can readily be determined. After a soaking rain or a heavy irrigation, cover the surface of a well-drained soil to reduce evaporation losses and wait two or three days. At this time the surface soil moisture is at the field capacity. In atmospheres of tension this is one-third (about 5 pounds per sq. inch).

The amount of moisture held at field capacity is approximately equal to the *moisture equivalent*. The moisture equivalent refers to the percentage water retained by a one-centimeter-thick moist layer of soil in a screen-bottomed container, when subjected to a centrifugal force of 1,000 times gravity for half-an-hour. The relationship between field capacity and moisture equivalent is more true in the case of loamy soils.

Between the wilting percentage (15 atmospheres) and the field capacity (1/3 atmosphere), the water is available to the plants. This is the range of moisture with which the agriculturist is primarily concerned.

Another term commonly used in soil-water relationship is *maximum water holding capacity*. It is the amount of water held in the soil when all pores are filled and when drainage is restricted. Under natural conditions only poorly drained soils are at their maximum water holding capacity for long periods of time.

Some relationships among the several soil moisture constants and different ways of expressing their soil-moisture tension are given in Table 3.2 and Figure 3.5.

TABLE 3.2
RELATIONSHIP AMONG SEVERAL MOISTURE CONSTANTS AND METHODS OF EXPRESSING SOIL-MOISTURE TENSION*

Appearance of soil	Type of soil water	Moisture Tension Equivalents: Centimeters of water column height	pF	Bars or Atmospheres (Approx.)	Approximate pounds per sq. inch	Soil moisture constants
	Gravitational or excess water	1	0	0.001	0.015	Maximum water holding capacity
WET	subject to	10	1	0.01	0.15	
	drainage, mainly	100	2	0.1	1.5	
	held in macropores	341	2.5	0.33	4.95	Field capacity
		500	2.7	0.5	7.5	
	Moisture available	1,000	3.0	1.0	15.0	
MOIST	to plants, mainly	10,000	4.0	10.0	150.0	
	held in micropores	15,496	4.2	15.0	225.0	Wilting point
		31,623	4.5	31 0	465.0	Hygroscopic coefficient
	Moisture unavailable to plants,	100,000	5.0	100.0	1,500.0	
		1,000,000	6.0	1,000.0	15,000.0	Air dry
DRY	held in extremely thin films around colloidal particles	10,000,000	7.0	10,000.0	150,000.0	Oven dry

Adapted from Kohnke, H., *The Practical Use of the Energy C*
Soil Science Society of America Proceedings 11: 64-66. 1947.

8. MEASURING SOIL MOISTURE

Water in a soil may be measured in a number of ways. These methods include :

1. **Gravimetric method.** This consists of obtaining a moist sample, drying it in an oven at 105°C until it loses no more water, and then determining the percentage of moisture as follows :

$$\% \text{ moisture} = \frac{\text{Loss in weight}}{\text{Oven-dry weight}} \times 100.$$

Mostly the moisture content of soils at various moisture levels is presented on an oven-dry weight basis of soil. Moisture content values are not calculated on wet-weight basis because the base of comparison (wet soil) is always variable. The gravimetric method is time consuming and involves laborious processes of sampling, weighing, and drying.

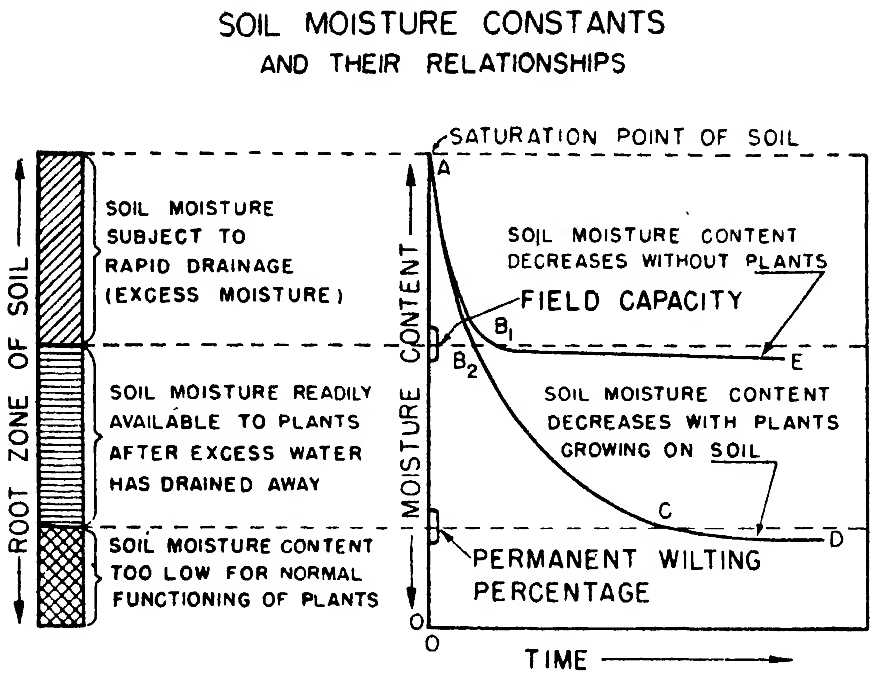

Fig. 3.5 The relationships among the saturation point, field capacity, and permanent wilting percentage in the root zone of a soil (*Redrawn from Edlefsen and Anderson, in Hilgardia, 15 : 2*)

2. **Equilibrium Tension** methods that depend upon measuring the soil moisture with the use of a porous clay cup (tensiometer) filled with water. The water in the porous cup is attached to a vacuum gauge or a mercury manometer. As the soil dries out, water moves through the porous cup, setting up a negative tension or vacuum. These tension readings are then calibrated to interpret the percentage of moisture. Tensiometers are the only direct way of measuring soil moisture tension and soil moisture stress in the field. The principal limitation in the use of tensiometers is the very low range of tension (field capacity to capillary saturation) that they can measure. The actual range is from 0—0.85 atmospheres, or equivalent to suctions of less than 850 centimeter or pF 2.9. Once air gets entrapped into the tensiometer, the reliablility of readings is questionable. The tensiometers are more useful for measuring moisture in sandy soils than in fine textured soils.

Pressure membrance and porous plate techniques are used to make moisture determinations over a larger range of 1 to 15 atmospheres. (See Figure 3.6.)

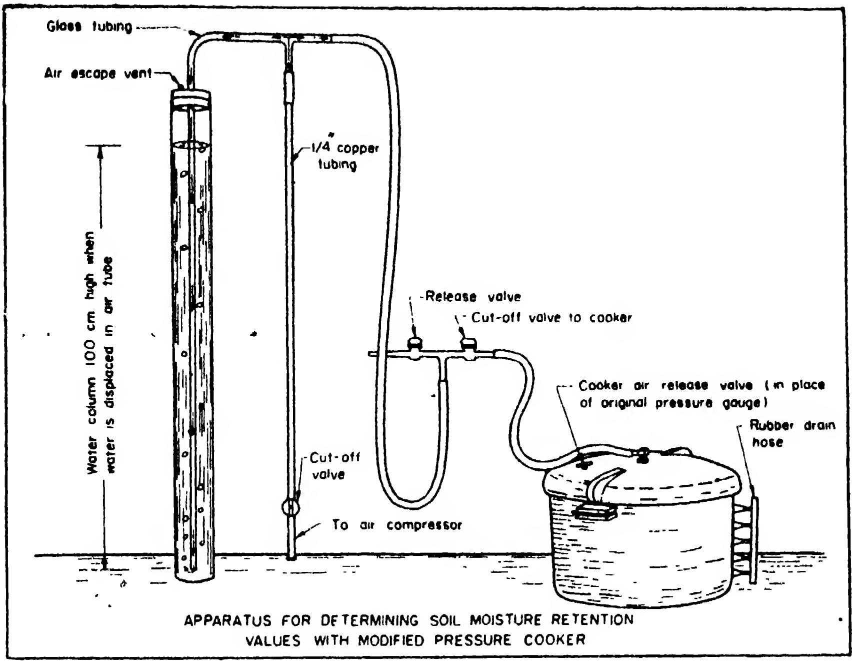

Fig. 3.6 Apparatus for determining soil moisture retention values with modified pressure cooker.

3. **Electrical Conductivity** methods that are based upon the changes in electrical conductivity with changes in soil moisture. A gypsum block inside of which are two electrodes at a definite distance apart are used in these methods. These blocks require previous calibration for uniformity. The blocks are buried in the soil at desired depths and the conductivity across the electrodes measured with a modified Wheatstone bridge. With proper calibrations, the percentage of moisture from the field capacity to the wilting percentage can be readily determined.

Improved blocks have been made of nylon or Fiberglas as they do not deteriorate in the soil as do gypsum blocks and are also more sensitive. However, these electrical measurements are affected by the salt concentration in the soil solution and are not very helpful in soils with high salt contents. The gypsum blocks in comparison with nylon or Fiberglas blocks are less affected to some extent by the presence of salt content on electrical conductivity. To overcome the affects of salts on conductivity readings, electro-thermal methods which determine heat conductivity are also sometimes used.

4. **Neutron Scattering** method is based on the ability of water to absorb fast neutrons from a radioactive source and return slow neutrons back to the detector. This method is presently being used in soil moisture investigations and is being improved.

Except for the gravimetric method, all other methods can be used in the field, and moisture determinations can be made *in situ* for any depth of soil. Suitable calibrations are necessary to convert the tension or other instrument readings into per cent moisture content. These indirect methods are very useful in determining when to start irrigating and when to stop.

9. MOISTURE CALCULATIONS

The soil moisture calculations in percentages on a weight basis have been commonly used, but this does not give a true picture of soil moisture relationships. Two soils may have similar moisture content on a weight basis but not on a volume basis. Calculations on a volume basis are more meaningful because water is retained in the soil within a given volume and roots also obtain moisture from a volume of soil. Further, soil moisture calculations on a volume basis can be easily converted into inches per foot or acre-inches which are of more practical significance for water use and management.

To change percentage soil moisture on a weight basis to percentage soil moisture on a volume basis, the calculation is as follows :

$$\% \text{ moisture by weight} \times \text{bulk density} = \% \text{moisture by volume}$$

When calculated for a depth of 12 inches, this value indicates water in inches per foot depth. On an acre basis, this value is written as acre-inches per acre-foot of soil. For example, a soil of one foot depth with 30 per cent moisture content by weight and a bulk density of 1.3 will have $0.30 \times 1.3 \times 12 = 4.68$ acre-inches of water for one foot depth.

For rough calculations one-acre foot of soil is assumed to have a weight of 4,000,000 pounds. Another approximate moisture calculation on an acre-inch basis for soil depth of one foot is :

$$\frac{\text{Acre inches of water}}{\text{per foot of soil depth}} = \frac{\% \text{ moisture on weight basis} \times 4{,}000{,}000}{225{,}512 \text{ (pounds of water/acre-inch)}}$$

$$= \% \text{ moisture on weight basis} \times 17.74$$

When moisture values for maximum water holding capacity, field capacity, wilting point, and bulk density of a soil are available, many useful calculations of practical significance can be derived concerning the moisture characteristics of a soil.

The following example would illustrate this :

Example : Suppose that a soil has the following values for an acre-foot depth :

Max. water holding capacity	=	45 per cent
Field capacity (1/3 atm.)	=	23 per cent
Wilting point (15 atm.)	=	9 per cent
Bulk density	=	1.4 gms/cubic cm.

Then,

(i) At maximum water holding capacity, this soil will retain water as :
$0.45 \times 1.4 \times 12 = 7.56$ inches per acre-foot.

(ii) As drainable water is the difference between maximum water holding capacity and field capacity (45—23=22%), the water that could drain out or percolate will be :
$0.22 \times 1.4 \times 12 = 3.70$ inches per acre-foot.

(iii) As available water for plant growth is the difference between field capacity and wilting point (23—9=14%), the available water will be :
$0.14 \times 1.4 \times 12 = 2.35$ inches per acre-foot.

(iv) Unavailable water which is represented by wilting point (9%) will be :
$0.09 \times 1.4 \times 12 = 1.51$ inches per acre-foot.

10. AVAILABLE WATER

Available water is the range of soil moisture between the wilting percentage (lower limit) and the field capacity (upper limit). This is approximately equal to the capillary water, as it is mainly held in capillary-sized pores. For crop growth purposes, this is the most important range of soil moisture.

Table 3.3 shows the generalized relationships that exist among the wilting point, field capacity, and available water capacity of eight soil textural classes. With increasing amount of clay in a soil, its capacity to hold water at both the wilting point and field capacity increases. The same is true for the available water capacity up to the fineness in soil texture of a

TABLE 3.3
WILTING POINT, FIELD CAPACITY, AND AVAILABLE WATER CAPACITY OF VARIOUS SOIL TEXTURES*

Soil Texture	Wilting Point		Field Capacity		Available Water Capacity	
	per cent	Water per foot of soil depth (inches)	per cent	Water per foot of soil depth (inches)	per cent	Water per foot of soil depth (inches)
Medium sand	1.7	0.3	6.8	1.2	5.1	0.9
Fine sand	2.3	0.4	8.5	1.5	6.2	1.1
Sandy loam	3.4	0.6	11.3	2.0	7.9	1.4
Fine sandy loam	4.5	0.8	14.7	2.6	10 2	1.8
Loam	6.8	1.2	18.1	3.2	11.3	2.0
Silt loam	7.9	1.4	19.8	3.5	11.9	2.1
Clay loam	10.2	1.8	21.5	3.8	11.3	2.0
Clay	14.7	2.6	22.6	4.0	7.9	1.4

**Source* : *Water.* The Yearbook of Agriculture, 1955, page 120, U.S. Department of Agriculture.

Note : It is obvious that since there is a variation in the amounts and kinds of sand, silt, and clay within any one textural group (such as within loam soils), there is also a variation in the water constants ; however, for purposes of simplification, an average value is given in this table.

silt loam. In a clay loam and in a clay, however, the available water capacity *decreases* from that in a silt loam. This relationship is also shown graphically in Figures 3.7 and 3.8.

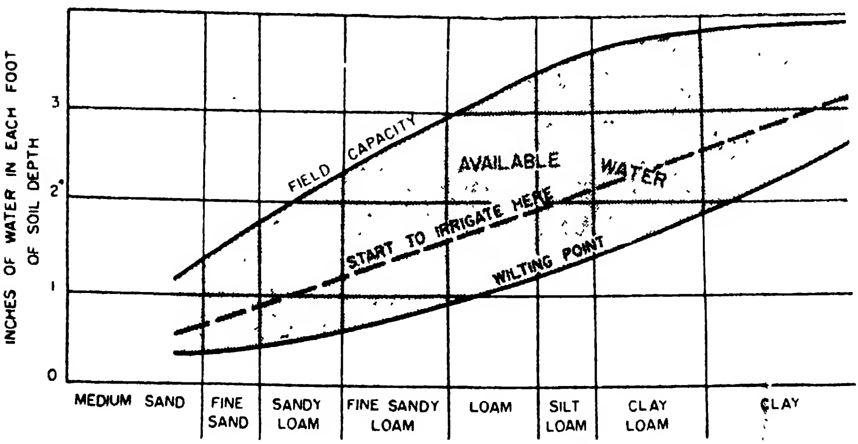

Fig. 3.7 Inches of water capacity in each foot of soil depth in relation to soil texture and the soil moisture constants. Also an indication is shown as to when to start irrigating each soil texture. (*Source : Water.* The Yearbook of Agriculture, 1955 U.S.D.A.)

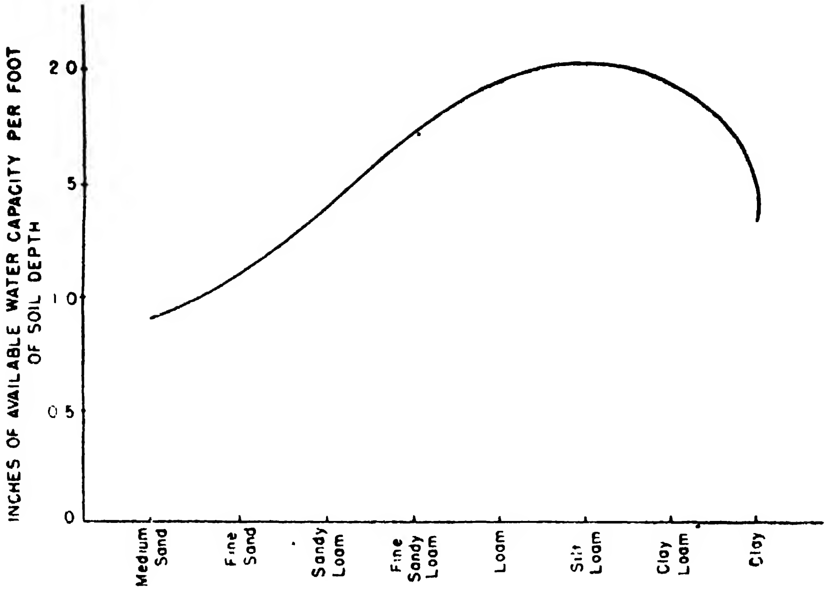

Fig. 3.8 Inches of available water capacity per foot of soil depth in relation to soil texture. (*Source : Water.* The Yearbook of Agriculture, 1955, U.S.D.A.)

When a plant permanently wilts the water remaining in the soil will vary in amount depending primarily upon the texture of the soil. In sandy soils the amount of water remaining at the wilting point may be about 0.5 inch per foot of soil depth. In loam soils, the amount may be 1.5 inches and in clay soils about 2.5 inches per foot of soil depth.

The amount of water to apply to a soil at the wilting point to reach the field capacity is called the "available" water capacity. The available water capacity also varies primarily with soil texture; for example, it is about 1.2 inches for sandy soils, 2.0 inches for loams, and 1.6 inches for clay soil per foot of soil depth.

II. SOIL WATER LOSSES

The soil water losses occur mainly through percolation, evaporation, and transpiration. In soil water management, suitable practices are necessary to reduce water losses as far as possible and to make the best use of available water resources.

Percolation losses are maximum under humid climates with high rainfall. Water loss through percolation is necessary otherwise poor drainage conditions and water logging may develop. The drainage practices are

necessary for proper plant growth in order to relieve badly drained soils of their excessive water. However, reduction of percolation losses under irrigated agriculture is important. Percolating waters also leach out important plant nutrients from soil. Such nutrient losses can be minimised to some extent by adopting suitable cropping practices.

Evaporation losses are dependent upon temperature, humidity, wind velocity, and soil conditions. Man can affect maximum control over such losses by adopting suitable soil management practices. The basic principle is to keep the soil under a vegetative cover. Agricultural practices such as mulching, certain tillage operations, and wind breaks, can help to reduce evaporation losses.

Transpiration losses of water are through the stomata of leaves. Transpiration is a physiological phenomenon and plants must transpire for their growth. The ratio between the units of water transpired to produce one unit of dry plant matter is called *transpiration ratio*. Transpiration, like evaporation, is also influenced by temperature, humidity, wind velocity, moisture contents in the soil, and inherent characteristics of the plant. Different plant species and even different varieties of the same species differ in their transpiration rates. Transpiration being a natural characteristic of the plant, man has practically very little control over it. However, in water scarcity areas, crop selections can be made that have low transpiration ratios. In crop husbandry, undesired transpiration losses through weeds should be checked by proper weed control.

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CHAPTER FOUR

WEATHERING AND SOIL FORMATION

> *"The geological deposit, the glacial till, the sandy deposits of the sand plains, the lake-laid or marine clays, sands, silts, and gravels, the residual earth resulting from rock decay constitute soil materials or parent materials of soils".*
>
> C. F. MARBUT, 1923.
>
> *"A mature soil is one that has assumed the profile features characteristic of the predominant soils on the smooth uplands within the general climatic and botanic region in which it is found".*
>
> C. F. MARBUT, 1926.

Soils that form the thin outer covering of the earth have directly or indirectly developed from the mineral constituents of the rock. Through the weathering processes, both physical and chemical, activised by the atmospheric agencies, the rocks disintegrate and decompose to produce the unconsolidated parent material ; which in turn, under the influence of pedogenic (soil-forming) processes, ultimately develop into soil. From rocks to the formation of soil the processes could be summarized as follows :

ROCKS AND MINERALS → PARENT MATERIAL → SOIL PROFILE

WEATHERING

← - - - - - - - - - - - →

SOIL GENESIS

← - - - - - - - - - - - →

Although in simple terms it means that weathering precedes soil profile development, no distinct line can be drawn where weathering stops and soil forming processes or genesis commence. Soil formation does not always wait on weathering. In fact, the two processes proceed simultaneously.

Fig. 4.1 Rocks weather into parent material which in turn develops into a soil, under the pedogenic processes. This soil has developed from sandstone, under a forest cover, and under 60 inches of annual rainfall in central India.

Weathering is normally considered to be a geological process which is essentially *destructive* and is mainly physico-chemical in nature. Weathering processes are analytical and lead to simplification of substances, the final products being simple compounds. On the other hand, soil formation is a *constructive* process of bio-geochemical nature encompassing certain ~~biological~~ influences. Soil formation is more of a synthetic process leading to development of complex soil bodies.

The properties and characteristics of soils are influenced by the types of rocks and their mineral constituents, nature and the process of their weathering, and their predominant soil-forming factors. Productive soils usually develop from rocks and minerals plentiful in essential plant food elements. Natural vegetation also plays its role in developing the soils. (See Figure 4.1.) But intense weathering and leaching may produce less productive soils even from rocks and minerals which were originally rich in essential elements. Soil formation processes under tropical conditions where the temperatures are high and rainfall heavy, are quicker and differ in many respects from soil formation under temperate conditions. A study of rocks and minerals in relation to their composition and degree of susceptibility to weathering is thus an important aspect of pedological studies under tropical conditions.

1. ROCKS AND MINERALS

A mineral is a substance that occurs in nature with distinct physical and chemical properties, such as quartz (SiO_2), orthoclase ($KAlSi_3O_8$), and calcite ($CaCO_3$).

Rocks are mixtures of minerals, and therefore their physical and chemical composition vary with the characteristics of minerals present in them. On

the basis of their genesis and structure, rocks are generally grouped into three classes, namely, igneous, sedimentary, and metamorphic.

Igneous rocks are formed by solidification of molten magma from the interior of the earth. They are called *plutonic* when the magma solidifies at great depths ; *intrusive* or dike rocks when it solidifies at moderate depths ; and *extrusive* or effusive when solidification takes place on the surface of the earth as a result of volcanic activities. Characteristic types that weather to important soil materials are granite, syenite, basalt, andesite, diabase, and gabbro.

Sedimentary rocks have formed from the consolidation of sediments accumulated through wind or water action at the surface of the earth in past geological ages. When these rocks are formed from mechanical sediments they are called *clastic*. Others are formed through chemical reactions, primarily precipitates from aqueous solutions. A few important examples are limestone, sandstone, siltstone, shale, conglomerate,. calcareous sandstone, and arenaceous limestone.

Metamorphic rocks have resulted from the subsequent transformation of igneous and sedimentary rocks under the influence of heat, pressure, and chemically active liquids and gases. Some important types of metamorphic rocks that are sources of weathered parent material for soil formation are gneiss from granite, slate from shales, marble from limestone, schist from shale, and quartzite from sandstone.

Rocks are also classified on the basis of their silica content, such as :

Acid rocks, containing 65-75 per cent silica, e. g., granite, rhyolite, sandstone, and gneiss.

Intermediate rocks, with 55-65 per cent silica, e. g., syenite, diorite, and andesite.

Basic rocks, having 40-55 per cent silica, e. g., gabbro, basalt, limestone, and diabase. These are also rich in iron, calcium, magnesium, and sodium.

During weathering processes, it could be generalized that all rocks are subject to losses and gains, the net result being a loss. Even under similar environmental conditions, rocks neither lose equally nor weather equally. Rocks having a complex mineral composition weather more easily. Acid igneous rocks weather slowly as compared to basic igneous rocks.

Daikuhara* has listed the rocks in order of their decomposition as :

Basalt > Gneiss > Granite > Hornblende > Andesite.

Generally, acid igneous rocks produce soils with good physical conditions,

*Jenny, H., *Factors of Soil Formation*. McGraw-Hill Book Company, Inc., New York and London, 1941.

while soils from basic rocks possess favourable chemical characteristics; for example, soils from basalt are richer in phosphorus and lime than soils from granite.

Sedimentary rocks, in general, do not weather as rapidly as igneous and metamorphosed igneous rocks. Sandstone is more resistant than limestone. Soils developing from highly calcareous parent rocks weather rapidly but take much longer time to attain a mature profile.

Most of the rock examples given are found in Tropical Asia. The extra-peninsular region of India, including the Himalayan mountains, is predominantly made up of sedimentary rocks. Basalts are found in most of the countries in Tropical Asia. Young volcanic ash is common in the islands of Indonesian archipelago. In Philippines, basic types of rocks are more common and extensive. True granites are uncommon. It is reported that nearly 20 per cent of the total area of Philippines is covered with younger portions of volcanic ash. In Cambodia the common acid rocks are conglomerates, sandstones, and shales and the predominant basic rocks are volcanic basalts, limestone, and apatite.

2. SOIL-FORMING MINERALS

Minerals have been variously classified on the basis of their composition, structure, colour, hardness, and specific gravity. The main interest in soil-forming minerals is with special reference to their composition and weatherability. Soil-forming minerals are mainly alumino-silicates.

According to Clark*, the approximate proportion of major minerals in the earth's crust is: felspars 58 per cent; amphiboles and pyroxenes 16 per cent; quartz 13 per cent; and micas 4 per cent. The remaining portion consists of accessory minerals such as zircon, ilmenite, apatite, titanite, pyrite, magnetite, and rutile. It is thus seen that felspars constitute by far the largest part of soil-forming minerals. A majority of the soil-forming minerals are light (in weight) minerals with specific gravity less than 2.9.

Felspars belong to the group of minerals that are light in weight, and are divided into orthoclase and plagioclase. In orthoclase, potassium is prominent. Plagioclase is divided into albite (high in sodium), anorthite (high in calcium), and oligoclase which consists of both albite and anorthite. Plagioclase weathers more rapidly than orthoclase.

Pyroxenes and amphiboles are ferromagnesian minerals belonging to

*Clark F. W., *Data of Geochemistry*. U. S. Geological Survey Bull. 770. 1924.

the heavy group. Pyroxenes are common in heavy basic rocks, and one of the important minerals is augite. The amphiboles are common in more acidic rocks and include hornblende and olivine. Pyroxenes being more basic in character weather more rapidly than amphiboles.

Micas occur both as primary minerals in igneous rocks and as secondary minerals in altered products of felspars and other minerals. The two important types are muscovite (white mica) a potassium aluminium silicate, and biotite (black mica) a potassium, aluminium, magnesium, iron silicate. Biotite weathers more rapidly than muscovite.

Quartz is another mineral which is widespread, occurring both as a primary mineral and as altered products of other minerals. It is one of the most resistant minerals. Serpentine, a hydrous magnesium silicate, occurs more commonly as a secondary product. Garnets are characteristic of metamorphic rocks and are very hard and very resistant to weathering.

A few of the important nonsilicate minerals are *calcite* ($CaCO_3$), magnesite ($MgCO_3$), dolomite ($CaCO_3 \cdot MgCO_3$), and gypsum ($CaSO_4 \cdot 2H_2O$).

Clay minerals have been synthesised from residual products of weathering, are colloidal in nature, usually crystalline, and are very important constituents of soils. Most of the physico-chemical and morphological properties of soils are influenced by these clay minerals. Clay minerals are hydrous aluminium silicates, frequently with some replacement of aluminium by iron and magnesium. The two most important groups of clay minerals are kaolinite; nonexpanding clays with a two layer lattice structure of Si-Al, and montmorillonite, expanding clays with a three layer lattice structure of Si-Al-Si. The other important clay minerals are illite, beidellite, and nontronite.

The approximate composition and weatherability of common minerals are given in Table 4.1.

3. WEATHERING PROCESSES

Weathering is an inevitable natural process of breakdown and transformation of rocks and minerals into unconsolidated residues, called *regolith*, lying on the surface of the earth, with varying depth. Weathering processes are distinguished into two types, namely physical and chemical. These processes had been going on long before life appeared on the earth to change the trend of weathering due to biological factors into a bio-geochemical one, leading to soil genesis.

TABLE 4.1
CHEMICAL COMPOSITION AND WEATHERABILITY OF COMMON MINERALS*

Mineral	Chemical composition	Weatherability
Quartz	SiO_2	Very low
Orthoclase	$KAl\ Si_3O_8$	Low
Albite	$Na\ Al\ Si_3O_8$	Low
Anorthite	$Ca\ Al_2Si_2O_8$	Very high
Muscovite	$KAl_2\ (Al\ Si_3O_{10})\ (OH)_2$	Low
Calcite	$CaCO_3$	Soluble
Zircon	$Zr\ SiO_4$	Very low
Apatite	$Ca_4(PO_4)_3(Ca\ F,\ Cl)$	Medium
Serpentine	$Mg_3\ Si_2O_5(OH)_4$	Medium
Rutile	TiO_2	Very low
Titanite	$Ca\ Ti\ Si\ O_5$	Low
Garnet	$Ca_3Al_2\ (SiO_4)_3$	Low
Hornblende	$Ca_3Na(Mg,Fe)_6(Al,Fe)_3$ $(Si_4O_{11})_4(OH)_4$	Medium
Augite	$Ca(Mg,Fe)_3(Al,Fe)_4(SiO_3)_{10}$	Medium
Olivine	$(Mg,\ Fe)_2\ SiO_4$	Very high
Biotite	$K(Fe,Mg)_2(Al,Fe)(AlSi_3O_{10})(OH)$	Very high
Magnetite	Fe_3O_4	Very low
Ilmenite	$Fe\ Ti\ O_3$	Very low
Tourmaline	$NaFe_3Al_4B_2Si_4O_{18}(OH)$	Low

*Mohr, E.C.J. and Van Baren, F.A., *Tropical Soils*. Interscience Publishers Ltd., London, New York, 1959.

Joffe* states: "Strictly speaking there is no biological weathering. Essentially, it is physical and chemical weathering by biological agencies". Biological agencies accelerate chemical weathering by the production of carbon dioxide during respiration, and by acidic secretions by plant roots. Higher plants help to bring mineral elements from lower depths to the surface. Various types of microorganisms, for example, autotrophic ones, cause decomposition of rocks and minerals.

The processes of weathering are greatly influenced by the climate and the type of rock. Joffe* states that in the humid tropics, physical weathering, as a rule, is subordinate to chemical weathering. The intensity of weathering usually reduces as one goes downwards from the surface. Robinson** states: "The end-product of chemical weathering would be

* Joffe, J. S., *Pedology*. Pedology Publications, New Brunswick, New Jersey, U.S.A., 1949.

**Robinson, G. W., *Soils, their Origin, Constitution and Classification*. Thomas Murby & Co., London, 3rd edition, 1949.

reached when all silicic acid, alkalies, and alkaline earths have been removed. The residual material would then consist of a mixture of hydrated alumina and hydrated ferric oxide, together with original minerals such as quartz that are least affected by chemical weathering. Material approximately of this constitution may be found in many parts of the tropics and is termed *laterite* or *ferrallite*".

4. PHYSICAL WEATHERING (DISINTEGRATION)

Physical weathering is a mechanical process, causing disruption of consolidated massive rocks into smaller bits without any corresponding chemical change or formation of new products. Under very cold or hot and dry conditions, such as in the polar regions and deserts, physical weathering is more prominent.

Temperature and water are the two most potent agents of physical weathering. Wide diurnal and seasonal changes in temperature cause various shattering stresses due to differential expansion and contraction in surfacial layers of rocks, especially in the rocks which are more heterogenous in their mineralogical composition. The temperature changes also bring about exfoliation of the surface layers of rocks. (See Figure 4.2.)

Fig. 4.2 Concentric weathering (exfoliation) in a granite rock. (Central India)

Water causes physical weathering of rocks in many ways. When water freezes in rock joints and crevices, it expands to about 9 per cent of its volume, creating a shattering force of about 150 tons per square foot. This is a hydrothermal process caused by intermittent freezing and thawing and is

more predominant in cold regions. Falling rain drops and hailstorms with their beating force also cause some abrasion of rocks. The moving water has a tremendous transport capacity and can carry particles 64 times larger if the velocity of the current is doubled. Water carrying sediments in suspension or rolling them along the bottom of the stream exerts a strong scouring action that grinds the particles finer. Water through its erosional forces removes weathered parts of the rock, thereby exposing fresh surfaces to weathering. Glaciers, during their movement, cause a great deal of cutting and crushing of the bed rocks. Glaciers have been active in the very recent geological past in Tropical Asian countries, but presently are not active except in some parts of the Himalayan region of India. (See Figure 4.3.)

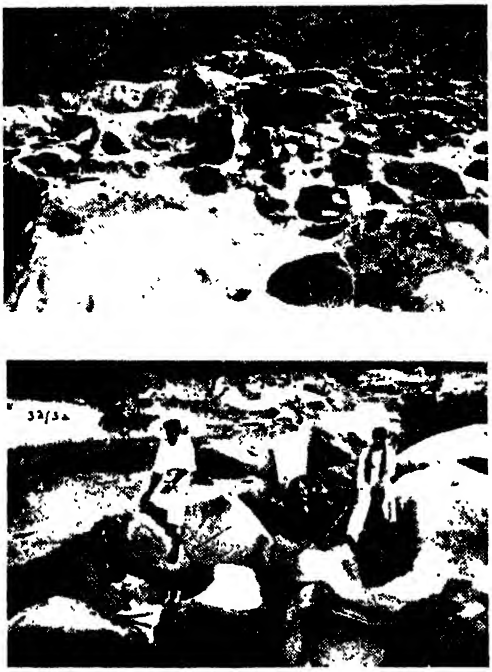


Fig. 4.3 The weathering action of flowing water results in abrasion. Scouring, pitting, and hollowing, are depicted here in : (above) Sandstone, and (below) Granite (India).

Wind, especially when laden with sand particles, causes abrasive action on exposed rocks. Wind in combination with ocean waves causes weathering along the sea coasts. Loosely balanced rock boulders sometimes roll down under gravitational force and break into pieces. Physical influences of biological agencies such as plant roots splitting the rocks apart ; movement of animals ; burrowing by rodents ; and cultivation by man, also help in mechanical weathering to some extent.

Under the predominant influence of physical weathering, soils usually consist of coarse materials and are often called *skeletal* soils.

5. CHEMICAL WEATHERING (DECOMPOSITION)

Physical disintegration is accompanied by chemical decomposition which produces changes in the nature and composition of rocks and minerals.

Chemical weathering takes place mainly at the surface of rock minerals, with the disappearance of certain minerals and the formation of secondary products. This is called chemical transformation. No chemical weathering is possible without the presence of water. However, the rate of chemical reactions increases with dissolved carbon dioxide and other solvents in water, and with increases in temperature. Thus, chemical weathering is at its minimum in desert areas due to lack of water and in cold regions due to low temperatures. The intensity of chemical weathering reaches its maximum in tropics where both water and temperature conditions are more favourable. The principal agents of chemical weathering are described below. For understanding of the individual processes, they have been described separately but in nature, they usually occur simultaneously.

Solution : Water is a universal solvent. Its solvent action is very much increased when carbon dioxide, organic and inorganic acids, or salts are dissolved in it. Most of the minerals are affected by the solvent or action of water. Soluble minerals such as halite (NaCl) dissolve readily. Solution helps in a continual loss of weathered materials but total removal by simple solution is negligible.

Hydration : Hydration means chemical combination of water molecules with a particular mineral. Soil-forming minerals occurring in rocks do not contain any water. They undergo hydration when exposed to humid conditions. A large number of minerals, especially of felspar, amphibole, mica, and pyroxene groups become hydrated, forming hydrous compounds, for example :

$$\underset{\substack{\text{Hematite}\\\text{(red)}}}{2Fe_2O_3} + \underset{\text{Water}}{3HOH} \rightarrow \underset{\substack{\text{Limonite}\\\text{(yellow)}}}{2Fe_2O_3 \cdot 3H_2O}$$

Hydration is always accompanied with increase in volume. Hydrated minerals usually become soft and more readily weatherable. Slaking of certain rocks is due mainly to hydration of their mineral constituents. Under drier conditions dehydration (the reverse process of hydration) can also occur.

Hydrolysis : Hydrolysis is one of the most important processes in chemical weathering. Hydrolysis depends on the partial dissociation of water into H-ions and OH-ions. Pure water has a very small amount of dissociation, but in the presence of carbon dioxide and mineral and organic acids in water solution, the H-ion concentration increases, resulting in the accelerated hydrolytic action of water. Hydrolysis is a double decomposition process and a hydroxide of some kind is usually formed. Water,

thus acts like a weak acid on silicate minerals, e.g.,

$KAlSi_3O_8$	+	HOH	$\rightarrow$	$HAl\,Si_3O_8$	+	KOH
Orthoclase		Water (dissociated)		Acid silicate clay		Potassium hydroxide

The products of hydrolysis are either wholly or partially leached by percolating water, depending on the climatic conditions and permeability of the residual materials. They may also recombine with other constituents to form clays. The hydroxides in the presence of carbon dioxide usually change into carbonates and bicarbonates. In a way, hydrolysis may be considered as the forerunner of clay formation.

Oxidation : This means addition of oxygen to various minerals. Oxidation is more active in the presence of moisture and results in hydrated oxides. Soil-forming minerals containing iron, manganese, and sulphides are more subjected to oxidation, e.g.,

$4FeO$	-	O_2	$\rightarrow$	$2Fe_2O_3$
Ferrous oxide		Oxygen		Ferric oxide (hematite)

Reduction : This means the removal of oxygen. Under conditions of excess water, such as may be encountered during floods or in saturated ground-water zones, oxygen is less plentiful and as a consequence, reduction takes place, e.g.,

$2Fe_2O_3$	--	O_2	$\rightarrow$	$4FeO$
Ferric oxide (hematite)	.	Oxygen		Ferrous oxide

Carbonation : Carbonic acid, although a weak acid of carbon dioxide, is a very important agent of chemical weathering as it makes minerals more soluble. The atmosphere contains only 0.03 per cent carbon dioxide, but the rain water may contain as high as 0.45 per cent carbon dioxide. Further, decomposition of organic matter liberates carbon dioxide in large amounts. Carbonation tends to produce carbonates and bicarbonates, e.g.,

$CaCO_3$	+	H_2CO_3	$\rightarrow$	$CaH_2(CO_3)_2$
Calcite (slightly soluble)		Carbonic acid		Calcium bicarbonate (readily soluble)

6. CLASSIFICATION OF PARENT MATERIALS

Parent materials from which soils are derived may be classified as residual, transported, or cumulose. *Residual* materials are those that have remained in place long enough for a soil to develop from them. *Transported* materials are mineral and rock fragments that have been moved in place by

one or more of these agencies : water, wind, ice, and/or gravity. *Cumulose* materials are peats and mucks that have developed in place from plant residues and have been preserved by a high water-table.

An outline may help to visualize the relationships among the parent materials.

I. *Residual material* (*Sedentary*)
   - A. Igneous—granite, basalt, and andesite.
   - B. Sedimentary—limestone, sandstone, and shale.
   - C. Metamorphic—marble, quartzite, and gneiss.

II. *Transported material*
   - A. Water
     1. Alluvial—running water
     2. Lacustrine—lakes
     3. Marine—ocean
   - B. Wind
     1. Aeolian
     2. Loess
   - C. Ice
     1. Moraine
     2. Till Plain
     3. Outwash Plain
   - D. Gravity—colluvial

III. *Cumulose material*—(organic) peat and muck.

7. RESIDUAL MATERIALS

When soils develop in place from underlying igneous, sedimentary, or metamorphic bed rocks they are termed to have formed from residual materials. Most of the Lithosolic soils, Red-and-yellow soils from the granite-gneiss-schist complex in Orissa (India), Andosols from volcanic ash materials in Philippines and Indonesia, and certain Grumsols on basalts, are some of the examples.

8. MATERIAL TRANSPORTED BY WATER

Materials that have been transported by water are classified as *alluvial, lacustrine*, or *marine.*

Alluvial materials are sediments that have been deposited by flowing water, such as by small streams or large rivers. If the material that lies

along the river is subject to periodic flooding the deposit is known as a *flood plain,* and such deposits are found to a certain extent beside every stream. Older deposits that were laid down by the river but are not now subject to flooding are called *terraces.* When much of the finer sediments carried by the stream are deposited near its mouth, they are called *delta* deposits which are often a continuation of the flood plain. Alluvial and delta deposits are well known in the Indo-Gangetic basin in India and Irrawady valley in Burma. These areas are agriculturally very important. In Taiwan there are many alluvial plains on the western side.

Lacustrine materials were deposited in fresh-water lakes. Depressions that were once filled with water have gradually become filled with mineral sediment. Some of the *lacustrine* materials found in Tropical Asia are in the former volcanic lake bottoms in Java, Sumatra, and Toule Sap Lake in Cambodia.

Marine materials are formed by the deposition of sediments carried into the ocean by rivers. As the land surface was uplifted or the ocean receded, the sediments became weathered into soil ; for example some of the Andaman Islands in India, and other islands in Tropical Asia.

9. MATERIALS TRANSPORTED BY WIND

Sand dunes and some deposition from present day dust storms are called *Aeolian* deposits. These occur, for example, in the Thar Desert covering the western parts of India and the adjacent parts of Pakistan. Soil materials that were deposited following the last glacial period are known as *loess.* Deep deposits of *loess* occur in the Pathwar Plateau in West Pakistan. (See Figure 4.4.)

Fig. 4.4 Will the town be buried ? Such sand dunes are common in the Thar desert of India and Pakistan. They cover about 28,000 square miles in India.

10. MATERIALS TRANSPORTED BY ICE

In Polar regions, as snow continued to accumulate, pressure from its weight changed the snow to ice. After centuries of such build-up, the ice, under tremendous pressure, moved outward. In moving across rocks, sand, silt, and clay, the glacial ice picked them up, making a mass of dirty and stony ice. Apparently there was a greater movement outward during the winter build-up of snow ; during the summer, the ice front melted. Water flowing from the melting ice carried sediments, while the larger rocks were dropped in place.

When the ice front melted about as fast as it advanced, deposits of sediment were built up, resulting in a series of stony hills at the ice margin. These are known as *moraines*. But when the ice front melted faster than it advanced, a smoother deposition resulted, known as *till plains*. Water gushing forth from a rapidly melting ice front carried fairly coarse sand particles and deposited them in a level plain. These are *outwash plains*. Some of the materials transported by ice may be found in the Himalayan region of India.

11. MATERIALS TRANSPORTED BY GRAVITY

Soil debris at the foot of a slope that moved there in response to gravity is called *colluvial* material. Colluvial material exists to some extent at the base of all slopes, but it is especially noticeable in mountainous topography where rock slides, slips, and avalanches are common.

12. CUMULOSE MATERIALS (PEAT AND MUCK)

Plant remains that for centuries have been preserved in shallow lakes are the peat and muck that exist today. *Peat* is the term used when the plants are recognizable ; when plants decay beyond recognition, the deposit is called a *muck*. Although not very extensive, cumulose materials are met with in patches in most of the Tropical Asian countries especially in back-water areas along the coast lines.

13. SOIL FORMATION

In a broad way, the transformation of rocks into soil may be termed as soil formation. Soil formation also starts simultaneously with the weathering

of the rocks. The weathering processes are primarily *destructive* in nature and help to change the consolidated rocks into unconsolidated material (parent material). The soil-forming processes are *constructive* and result in a soil profile that has been developed from the surface few feet of parent material.

14. FACTORS OF SOIL FORMATION

At any specific location on the surface of the earth, five factors are acting simultaneously to produce soil. These are :

1. Climate
2. Parent material
3. Relief
4. Biosphere
5. Time.

These factors are not of equal significance in soil formation. Although some of them may be more influential in determining the nature of soil development under a particular set of conditions, all of them are interrelated and complement one another. Their relationship to the soil properties has been expressed by Jenny* in the following equation :

$$S=f\,(cl, b, r, p, t, \ldots\ldots)$$

Where, S=any soil property, *e.g.*, clay content
f=function of or dependent upon
cl=climate
b=biosphere (vegetation, organisms, man)
r=relief (topography)
p=parent material
t=time (age)

Thus, any soil property is a function of the collective effects of all the soil-forming factors.

Joffe** divides soil formation factors into two kinds :

Passive factors—which represent the source of the soil-forming mass and conditions affecting it. They are parent material, relief, and time.

Active factors—which represent agents that supply energy that act upon the mass for processes of soil formation. They are climate and biosphere.

*Jenny, H., *Factors of Soil Formation*. McGraw-Hill Book Company Inc., New York and London, 1941.

**Joffe, J.S., *Pedology*. Pedology Publications, New Brunswick, New Jersey, U.S.A., 1949.

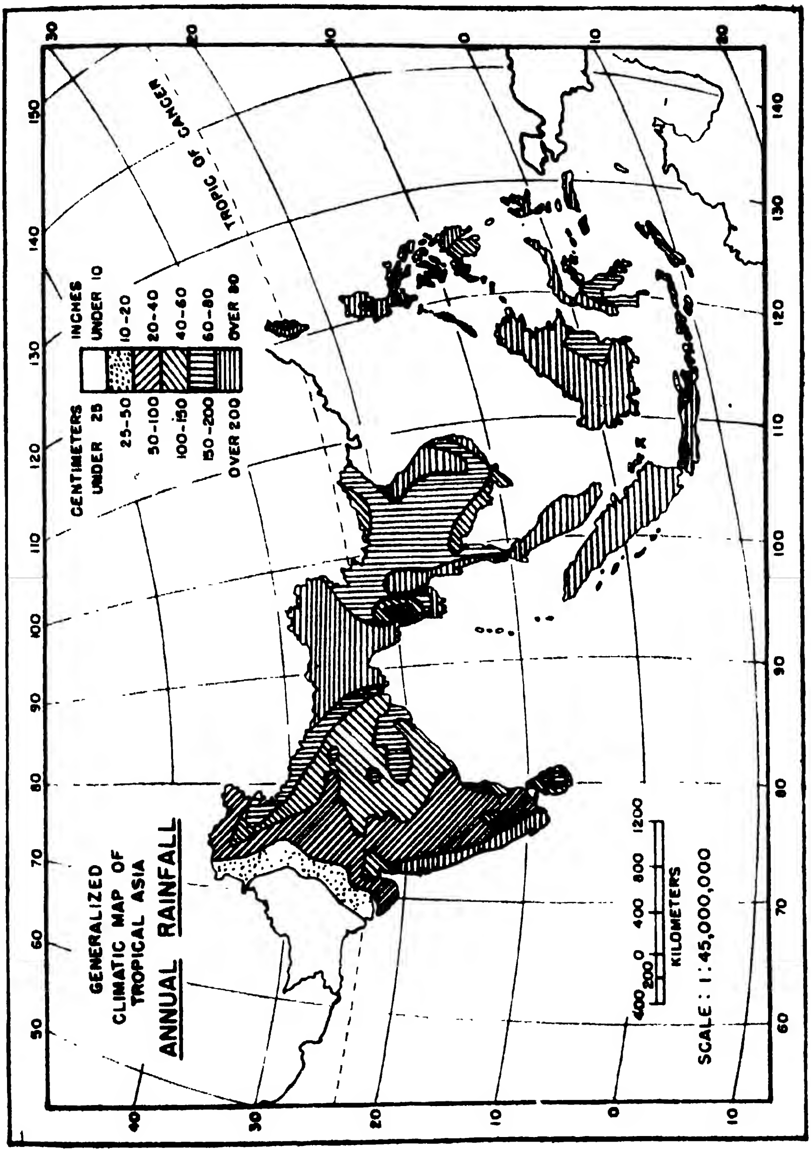


Fig. 4.5 Average Annual Precipitation in Tropical Asia. (*Adapted from: Goode's School Atlas, Rand McNally and Co New York, 1937.*)

15. CLIMATE AND SOIL FORMATION

Over the face of the earth, climate is the dominant factor in soil formation. Any soil profile is a result of both direct and indirect action of centuries of climatic forces. Climate influences soil formation largely through precipitation and temperature.

Precipitation : Precipitation primarily regulates the moisture-air regime of the soil and determines the leading trends in the soil profile, depending upon available percolating waters. Rainfall also affects profile development through erosion, producing thin soils on steep slopes and deposition of soil material down hill. The nature, intensity, frequency, and distribution of precipitation influence the course of soil formation. In general, with increasing moisture, nitrogen and carbon content, clay content, aggregation, saturation capacity, and exchangeable hydrogen tend to increase. On the other hand, exchangeable bases and pH values show a decrease with increasing moisture. The depth of the calcium carbonate horizon in pedocal (lime accumulating) soils increases with increasing moisture. Under Tropical Asian conditions, clay content shows a decrease with in increase rainfall possibly because of decomposition of clay to form secondaryconcretions. (See Figure 4.5.)

Sharma gives the following data for Punjab region in India showing the effect of rainfall on a few soil properties :

TABLE 4.2

THE RELATIONSHIP BETWEEN ANNUAL RAINFALL AND CERTAIN SOIL CHARACTERISTICS IN PUNJAB STATE (INDIA)*

Annual Rainfall (Inches)	District	Sample depth (Inches)	Clay per cent	pH	Total Exchange Capacity (m.e./ 100 gm. soil)	Total Ex-change-able Bases (m.e./100 gm. soil)	$CaCO_3$ per cent	Organic Carbon per cent	Total Nitrogen per cent
70—100+	Kangra	0—4	19.92	4.70	13.25	7.28	Nil	0.946	0.101
40—70	Gurdaspur	0—6	37.60	7.28	9.56	8.55	Nil	0.473	0.086
30—40	Karnal	0—6	50.00	6.89	9.55	8.51	0.17	0.510	0.072
20—30	Ludhiana	0—6	12.68	7.50	8.48	8.25	0.53	0.330	0.050
10—20	Sirsa	0—4	11.40	7.52	10.50	10.26	1.57	0.340	0.050

*Source : Sharma, Balkrishan, *A Study into the Nature of Soil Profiles Developed Under Different Climatic Zones of the Punjab.* Unpublished M.Sc. Thesis, Punjab University, 1953.

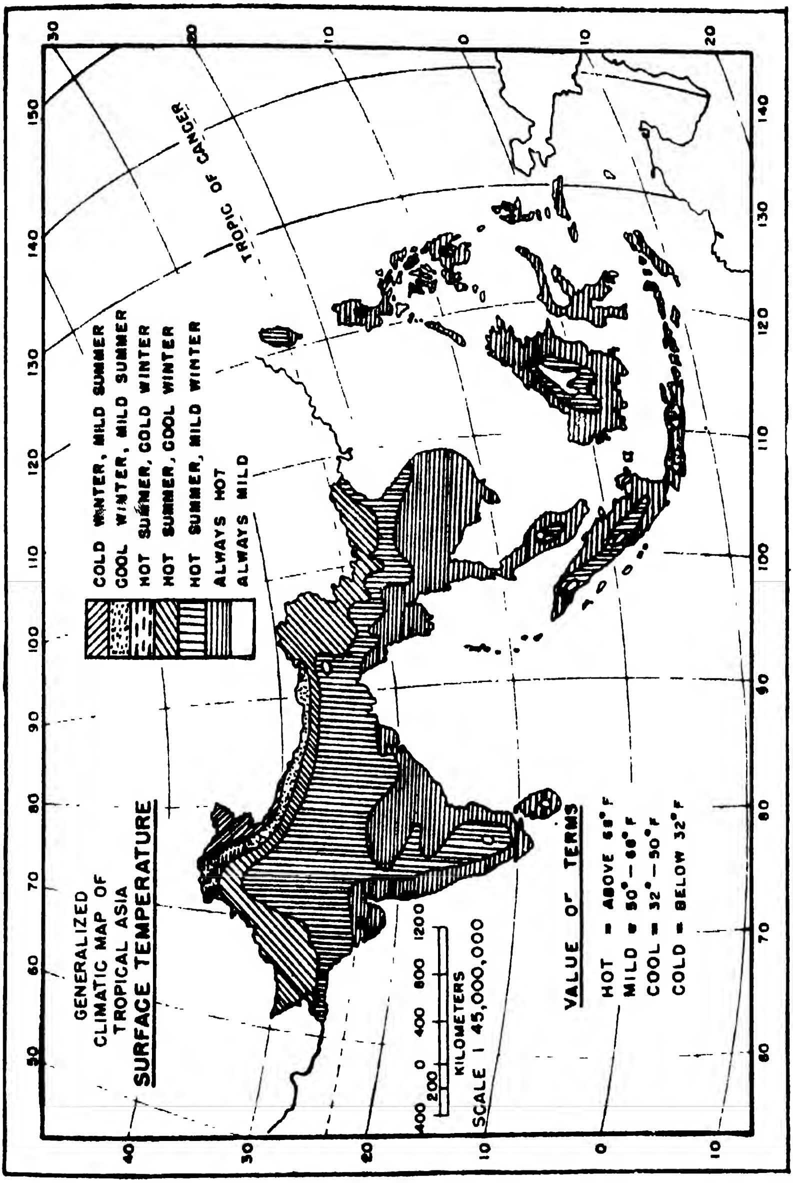


Fig. 4.6 Surface Temperatures during Summer in Tropical Asia. *(Adapted from: Goode's School Atlas, Rand McNally and Co., New York, 1937).*

Temperature : Temperature affects the velocity of chemical reactions which approximately doubles for every 10°C increase in temperature. It influences the organic matter decomposition and microbiological activities in the soil. Through evapotranspiration phenomena, temperature also determines the efficiency of rainfall. In general, with increasing temperature, the depth of weathering and clay content show an increase. On the contrary, nitrogen, organic matter, silica/alumina and base/alumina ratios tend to decrease with rising temperature.

Under tropical and subtropical climatic conditions, with high precipitation and long duration of weathering, highly leached soils have developed such as Ferallite or Laterite soils. Under certain humid tropical conditions, the weathered material develops considerable depth. Tropical soils, especially those developed from igneous and metamorphic rocks, have bright yellow or dark red colours because of intense hydration and oxidation, respectively, during their weathering. Tropical climates are generally favourable to the production of luxuriant vegetation, but high temperatures are not much favourable for the accumulation of organic matter in soils. Jenny, et. al.* while working on nitrogen and carbon contents of Indian soils, report that soil nitrogen and carbon rise with increasing mean annual precipitation in the hot coastal regions as also in the cool Himalayan ranges. But there is a strong negative correlation with mean annual temperature. Thus at higher elevations, the soils are much richer in organic matter than at sea level. (See Figure 4.6.)

Climatic Index : Many workers have attempted to express the relative effects of precipitation and temperature by a single factor or index in order to classify the climates and correlate them with soil formation. Using *precipitation-evaporation ratio*, Penck** has classified the climates as :

Arid—when evaporation is greater than precipitation.

Arid-humid boundary—when evaporation equals precipitation.

Humid—when evaporation is less than precipitation.

Lang's *rain-factor*** uses the ratio of mean annual rainfall in millimeters to the mean annual temperature in °C.

Meyer's *NS Quotient*** is the mean annual rainfall in millimeters divided by mean saturation deficit of air expressed in millimeters of mercury.

*Jenny, H. and Raychaudhuri, S. P., *Effects of Climate and Cultivation on Nitrogen and Organic Matter Reserves in Indian Soils.* Indian Council of Agricultural Research, New Delhi, 1960.

**Jenny, H., *Factors of Soil Formation.* McGraw-Hill Book Company Inc., New York and London, 1941.

Thornthwaite* has suggested *precipitation effectivenesss index* determined by the sum of quotients for each month. Crowther** has considered a *leaching factor* on the basis that to maintain a constant leaching, a rise of 1°C in temperature must be accompanied by an increase of 3.3 centimeters in rainfall. Ramann*** has suggested a *weathering factor* which is arrived at by multiplying the annual number of days with temperatures above freezing by the degree of dissociation of water. The weathering factor in tropical regions is about three times more than one in temperate regions. Mohr**** has tried to group the rainfall of Indonesia in dry and wet months. Sixty m.m. is taken as the limit; higher figures indicating *wet* months and lower ones, *dry* months.

Most of these climate indexes do not take into consideration the role played by runoff water. Further, many workers feel that it is the soil climate which is more important for soil formation than atmospheric climate. Apart from the macro-climatic considerations, micro-climate at a particular location also plays an important part in soil characterization.

The predominant effect of climate in the formation of soil is clearly reflected in many systems of soil classification which are based upon climate. One of the most important climatic systems of classification is by Vilensky** wherein soil groups have been classified on the basis of the combined effect of the precipitation-evaporation ratio and temperature.

Zonality in soils depending on climatic conditions is also evident in a lateral fashion from northern colder latitudes to the southern warmer latitudes. In mountainous regions vertical zonality is seen from low altitudes to higher altitudes as the temperature decreases with height and it is somewhat corresponding to south-north lateral zonality

Climate influences soil formation also indirectly, largely through its action on vegetation. Forests are the dominant vegetation in humid climates. The soil profile that develops in a forest has many more horizons than one that develops under grass. Semiarid climates encourage only

*Thornthwaite, C. W., *The Climates of North America.* Geog. Rev., 21 : 633—654, 1931.

**Crowther, E. M., *The Relationship of Climate and Geological Factors to the Composition of Soil Clay and the Distribution of Soil Types.* Proc. Royal Soc. B. 107 : 1-30, 1930.

***Jenny, H., *Factors of Soil Formation.* McGraw-Hill Book Company Inc., New York and London, 1941.

****Mohr, E. C. J. and Van Baren, F. A., *Tropical Soils.* Interscience Publishers Ltd., London, New York, 1959.

prairie grasses, and a deep, dark, uniform surface soil results. Arid climates supply only enough moisture for sparse, short, plains grasses which inadequately protect the soil against wind and water erosion.

16. CLIMATIC CONDITIONS IN TROPICAL ASIA

This region lies mainly between 10° south and 37° north latitudes, and between 62° and 130° east longitudes. Most of "Tropical Asia" belongs to the tropics, but the extreme northern parts of India, Burma, and Pakistan belong to the subtropics.

The most important feature of the region is its monsoon type of climate wherein the rainy season periodically alternates with dry periods. Both southwest and/or northeast monsoon are experienced in different parts. The effects of each monsoon are most pronounced on the windward side of the area. The seasonal variations in rainfall are common. The rainfall is usually in high intensities, thus, being more erosive in nature. The rainfall varies in different parts. The average annual rainfall in India is about 42 inches, received in an average number of about 51 rainy days. In Ceylon it is 80 inches, received in 157 days; and in Burma 121 inches in 142 days. The average annual rainfall in Taiwan is about 100 inches, in Cambodia 85 inches, and in Philippines about 150 inches. Average annual rainfall in Indonesia is about 100 inches. Nearly 91 per cent of the recording stations in Indonesia fall in the range of 40-160 inches. Some stations have recorded 4 to 7 consecutive dry months in a year. In general, the rainfall is highest in south eastern Indonesia and other islands, being over 80 inches annually. In some places in Indonesia over 300 inches of annual rainfall is also recorded. The rainfall decreases as one moves towards the northwest and it is below 10 inches annually in the Thar Desert part of India and Pakistan. (See Figures 4.5, 4.7 and 4.8.)

The highest annual recorded rainfall in the world, averaging nearly 426 inches, is in Tropical Asia, at Cherrapunji, Assam State, in eastern India. This station is at an elevation of 4,455 feet and is on the southern side of the Khasi Hills. But with even so much total annual precipitation, a definite dry season occurs during November (1.45 inches), December (0.20 inches), January (0.69 inches), and February (2.0 inches). The months of highest rainfall are June (95.72 inches) and July (99.52 inches), during the southwest monsoon. The excessively high rainfall has resulted in so much erosion that almost no vegetation and nearly-barren rocks exist in the area.

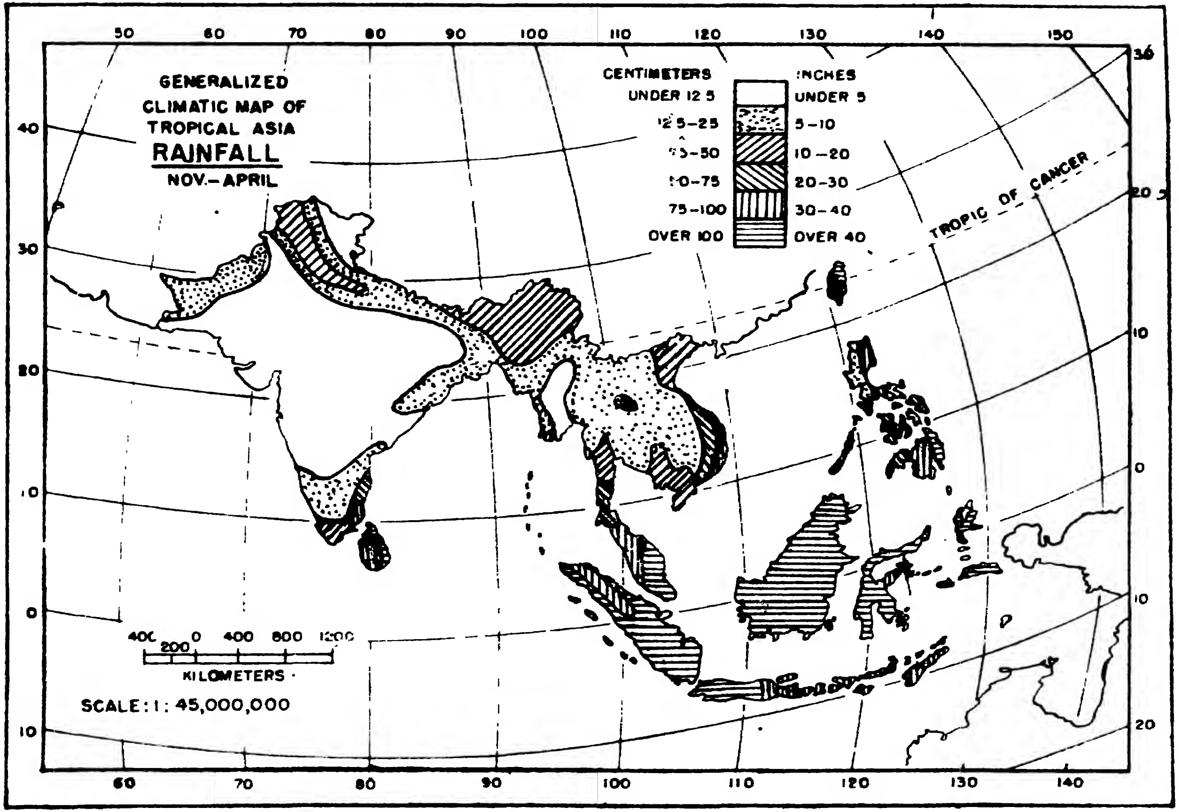


Fig. 4.7 Average Rainfall during the Southwest Monsoon Season, May-October. *(Adapted from : Goode's School Atlas, Rand McNally and Co , New York, 1937).*

Except at some high altitudes in mountainous areas, the mean annual temperatures within the tropics usually remain above 68°F (southern parts of Tropical Asia). In the subtropics they are above 68°F for about 4-11 months (northern parts of Tropical Asia), whereas, in temperate regions they range from 50°-68°F for 4-12 months (some mountainous regions). In general the summers are hot and winters are mild. (See Figure 4.6).

Thus, it could be seen that climatic conditions in the region are quite diversified. Although large areas have high rainfall, high temperature, and dense forests, there are also found deserts (Western India), swamps (around coastal and deltaic areas, and snow-clad mountains in the Himalayan region). These diversities consequently lead to much variation in the soils of the region.

17. PARENT MATERIAL AND SOIL FORMATION

Rocks on the surface of the earth are weathered until all essential elements become availabe to support lichens and other lower forms of plant life. As continuing generations of lichens grow, die, and decay, they leave increasing amounts of organic matter. Organic acids further hasten decay of the rock. With an increasing build-up of organic matter and of fine rock fragments, more rainwater is available for use by larger numbers of plants and animals.

In time, mobile materials near the surface will be leached downward and some of them deposited a few inches below the surface. The zone of deposition constitutes the beginnings of a B horizon. A few hundred more years, and the leached surface soil (A horizon) and the concentrated subsurface (B horizon) are well developed and are contrasting in nearly all characteristics. Surface erosion removes the top of the A horizon as fast as the A and B horizons slowly settle into the parent rock from whence they came. The soil is then in equilibrium with its environment and is called a mature soil.

Below the B horizon is the parent material, also known as the C horizon. In tropical climates, where rock decomposition may develop to great depths, it is often difficult to rightly designate the horizon of parent material.

The kind of soil that develops depends in part upon the kind of parent rock and parent material which influence the physical and chemical properties of the resultant soil. The effect of parent material on soil is stronger in the early stages of soil formation. With excessive leaching and advanced development, the influence of parent material on soil characteristics gradually decreases.

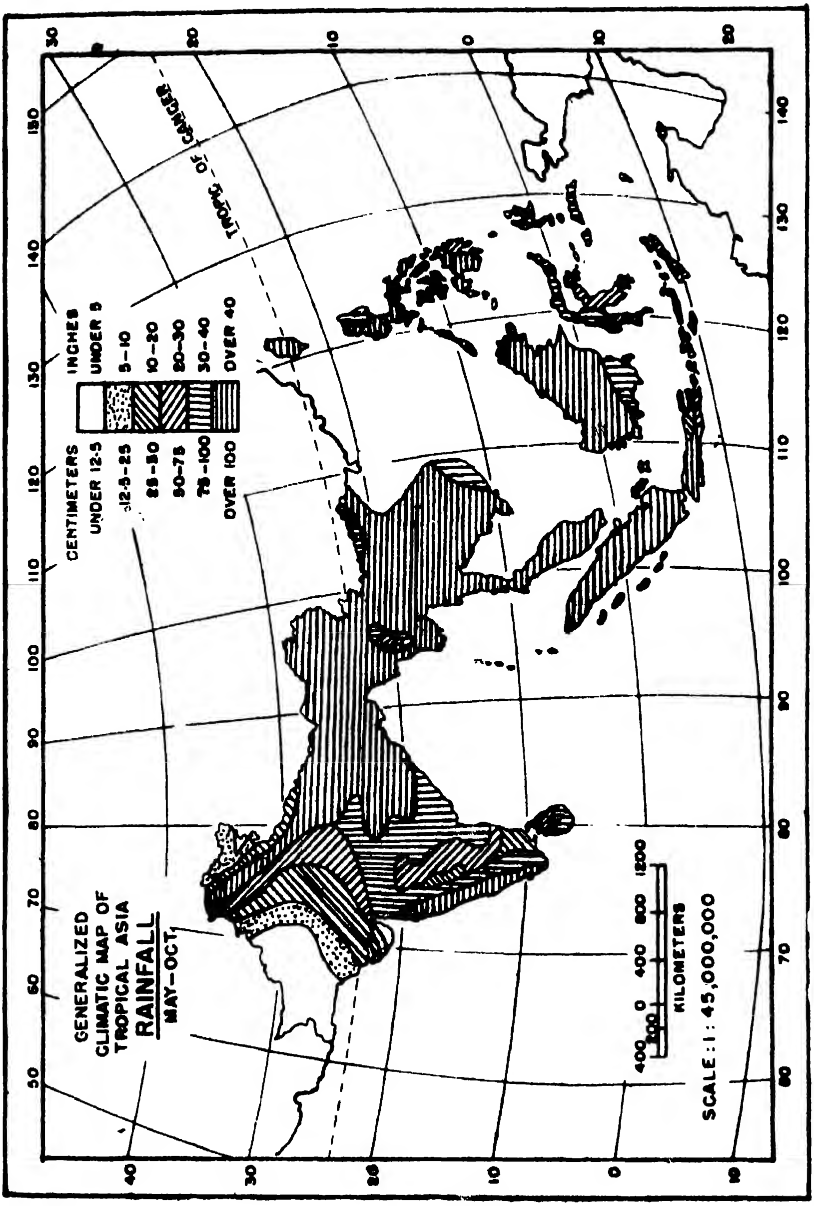


Fig. 4.8 Average Rainfall during the Northwest Monsoon Season. November -April. (*Adapted from: Goode's School Atlas, Rand McNally and Co., New York, 1937*)

Acid igneous rocks, quartzose grits, and sandstones usually weather slowly and give rise to coarse sandy soils with low base status, a kaolinite type of clay, and infertile soils. Most of the basic igneous rocks and sedimentary rocks normally weather to finer textured soils with high base status, montmorillonite type of clay, and fertile soils. Hard, pure limestones yield sandy, shallow soils (Terra Rossa), whereas impure soft limestones give rise to deeper and finer textured soils. In many Tropical Asian countries *Andosols* (high mountain soils) are usually found on volcanic ash under humid conditions.

In Tropical Asia where intense weathering is common it has been observed that similar soils may develop from such contrasting parent rocks as basalt, limestone, and granite gneiss. Tamhane, et. al*., have shown that black soils in India developed from basalt, limestone, granite gneiss and claystone under similar climatic conditions did not differ much in general physical and chemical properties.

In Tropical Asia the soils have developed mainly from granites, gneisses, basalts, sandstones, limestones, shales, volcanic ash, alluvial deposits of various natures, littoral (along the shore) deposits, and raised coral reefs. (See Figure 4.9.)

Fig. 4.9 Rocks on the surface of the earth are weathered until they support linchens. With further weathering, organic matter accumulates and sufficient nutrients and water become available to support higher plants (Top). Centuries more of weathering results in a true soil with definite horizons (Bottom).
(Note : The parent rock in both photos is granite) (India).

* Tamhane, R.V. and Namjoshi, N.G., *A Comparative Study of Black Soils formed from different Parent Materials.* Jour. Indian Soc. Soil Science 7: 49-63: 1959.

Parent materials formerly were a major basis for classification of soils and still is a dominant factor in the characteristics of young soils. However, the parent materials still form parts of certain soil classifications as would be apparent from such names as alluvial soils, basaltic soils, and limestone soils. The modern designations, however, should be : *Soils developed from* alluvium or limestone.

18. RELIEF AND SOIL FORMATION

Relief influences soil formation primarily as a factor affecting erosion and as a modifier of climate and water-air relationship in the soil. With increasing altitude, the climate becomes cooler and sometimes more humid. The vertical zonality in soils, to a large extent, is a function of topography. The southern aspects in the northern hemisphere are usually warmer. In Tropical Asian countries, the windward aspects receive more rainfall, such as on the western side of the western *ghats* in India.

Topography (relief) largely determines the drainage conditions and the ground-water level in the soil. Milne's *catena** concept, which represents a group of complex soils developed from similar parent materials, is primarily dependent upon topographical and hydrological conditions. Catenas are of common occurrence in tropical regions.

With the same kind of climate and parent material, soils that have developed on steep hillsides have thinner A and B horizons, This is because the surface erodes quite rapidly and less water moves downward within the profile. Soil materials on gently sloping topography have more water passing through them and the profile is generally deeper, the vegetation more luxuriant, and the organic matter level higher, than in soils on steep topography.

Materials lying in land-locked depressions receive run-off waters from above. Such conditions favour a greater production of vegetation but a slower decomposition of the dead remains ; the result is the existence of soils with large amounts of organic accumulations. If the area is wet at the surface for nearly the whole year, a peat or muck soil may develop.

In India where black and red soils occur in close proximity, it is observed that red soils occupy higher levels while black soils are at lower levels. Black soils in India have developed on broad plains with gently undulating slopes usually not exceeding 10 per cent.

* Milne, G. *A Provisional Soil Map of East Africa.* East Africa Agri. Res. Sta, 1936 (See also Morison, C.G.T., *The Caltena Concept and Classification of Tropical Soils.* Commonwealth Bur. Soil Sci. Tech. Comm. 46 : 124-127, 1949.

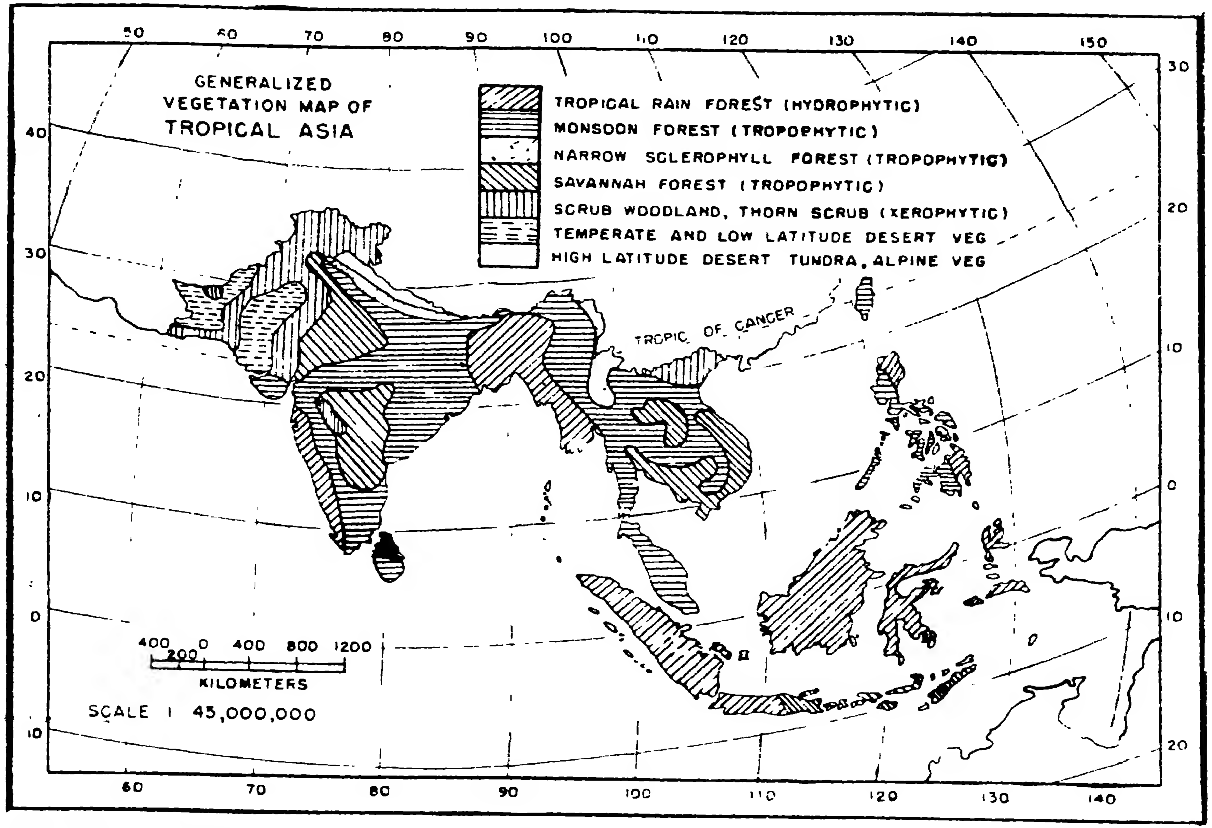


Fig. 4.10 Natural Vegetation in Tropical Asia. *(Adapted from: Goode's School Atlas, Rand McNally and Co., New York, 1937).*

In Tropical Asian countries, the topographic situation of soils is commonly used in the nomenclature and classification of soils. Such terms as soils of uplands, midlands, low lands, *tarai* (foot-hills) and mountains are commonly found in the literature.

19. BIOSPHERE AND SOIL FORMATION

Vegetation, microbes, animals, and man all greatly influence the soil formation processes. Vegetation is mainly not an independent soil forming factor as it itself is controlled by climate, soils and situation. Puri* states that in the tropical monsoon climate in India, the differences in vegetation on a regional scale are controlled by geological and soil conditions.

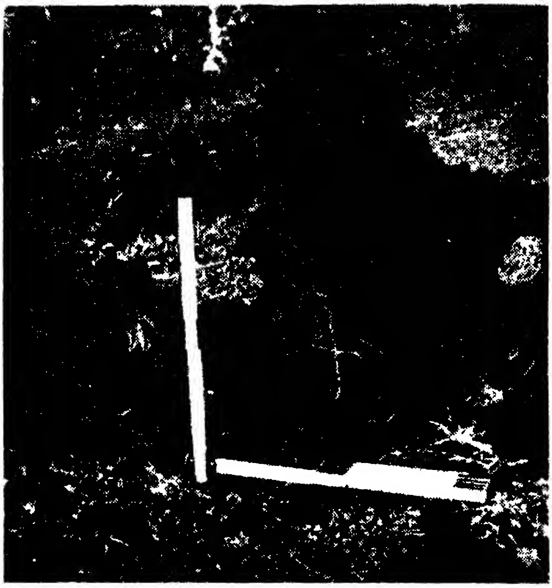


Fig. 4.11 Termites are a part of the biosphere that alter soil formation in Tropical Asia by retarding soil horizon development and by increasing soil productivity.
Top : Termite mound in West Central India.
Bottom : Soil from interior of termite mound in East Central India. Note the two white sponge like balls in cavaties, known as "ambrosia" or termite "garden", that is used as food for termites. Note also the alteration of soil structure as a result of termite activity. (Courtesy Julian Donahue)

The effect of vegetation is especially noticeable in the tension zone where trees

* Puri, G.S., *Edaphic Control of Vegetation on a Regional Scale in India.* Jour. Indian Soc. Soil Science 8 : 151-156 : 1960.

Fig. 4.12 Man's use of land also influences the trend of profile development. Bunding fields for rice paddy culture is very common in India and most of the Tropical Asian Countries.

and grasses meet. Vegetation exerts its main influence on soil formation through the amount and nature of organic matter that it adds to the soil. Soils developed under forest vegetation have more horizons, a more highly leached A horizon, and less humified organic matter than do soils which have developed under grass vegetation. Different kinds of microorganisms help in decomposition of organic matter. Forests usually predominate in humid regions ; desert shrubs in arid regions and grasslands in the transitional zone. Vegetation also aids in the control of erosion. (Figures 4.10, 4.11 and 4.12) (See also Figure 1.5.)

Burrowing animals, rodents, earthworms, ants, and termites, when present in large numbers are highly important in soil formation. They tend to interfere with the weathering processes which lead to distinct horizon differentiation. Burrowing animals cause constant mixing within the soil profiles. *Crotovinas*, which are abandoned passage-ways of rodents filled with soil, are important in certain soils.

Man through his land-use activities causes both deleterious and beneficial effects on the soil. He converts natural vegetation areas into agricultural lands. Unless judiciously used, human interference accelerates erosion especially through the activities such as burning, shifting cultivation, and indiscriminate grazing. Agricultural practices such as cultivation, puddling of paddy fields, cropping systems, use of manures, fertilisers, amendments, drainage irrigation, and reclamation, alter the general character of profile development.

20. TIME AND SOIL FORMATION

The length of time required for a soil to develop horizons depends upon many interrelated factors, such as climate, nature of the parent material,

burrowing animals, and relief. Horizons tend to develop faster under cool, humid, forested conditions. Acid sandy loams lying on gently rolling topography appear to be most conducive to rapid soil profile development.

Certain soils are termed mature or immature which give some idea of the time factor. But soil maturity is not mainly dependent upon weathering time. A mature soil reflects dynamic equilibrium with its environments.

Mohr has suggested five stages of weathering that are dependent on the mineralogical features of the soil.

Table 4.3

WEATHERING STAGES IN SOIL FORMATION*

Stage	Characteristics	Example from lateritic soils in Indonesia
1. Initial	Unweathered parent material	Fresh ash
2. Juvenile	Weathering started, but much of original material still unweathered	So-called 'Tarapan'
3. Virile	Easily weatherable minerals fairly decomposed, clay content has increased, slowly weatherable minerals still appreciable	Brown Earth
4 Senile	Decomposition arrives at a final stage, only most resistant minerals survive	Red Earth
5. Final	Soil development completed under prevailing conditions	Laterite

*Mohr, E.C.J. and Van Baren, F.A., *Tropical Soils*. Interscience Publishers Ltd., London and New York, 1959.

Time and degree of maturity are factors used in many systems of soil classification, *e.g.*, classification of soils into *zonal, intrazonal,* and a *azonal* soils. In India soils in the alluvial regions are classified on the basis of young alluvium (*Khadar*) and old alluvium (*Bangar*).

Under ideal conditions, a recognizable soil profile may develop within 200 years ; under less favourable circumstances, the time may be extended to several thousand years.

Factors which retard soil profile development are :

1. Low rainfall.
2. Low relative humidity.
3. High lime content of parent material.
4. Excessive sandiness, with very little silt and clay.

5. A high percentage of clay.
6. Resistant parent material, such as granite.
7. Very steep slopes.
8. High water-tables.
9. Constant accumulations of soil material by deposition.
10. Severe wind or water erosion of soil material.
11. Large number of burrowing animals.
12. All of man's activities, such as ploughing, liming, and fertilising.

In USDA Soil Survey Manual, the soil in relation to pedogenic factors has been described as follows: "Soil characteristics in any one place, result from the combined influence of climate and living matter, acting upon the parent rock material, as conditioned by relief, over periods of time, including the effects of the cultural environment and man's use of the soil."

21. SOIL-FORMING PROCESSES

The collective interaction of various soil-forming factors under a different set of conditions sets a course to certain recognised soil-forming processes. The ultimate result of soil formation is profile development. Specific profile features develop under particular soil-forming processes.

The fundamental processes that develop a profile are briefly described as follows:

Humification: Helps in the formation of the surface humus layer, called A_0 horizon. Its characteristics depend on the nature of vegetational residue and the way it becomes decomposed and synthesized into new organic compounds. The percolating water passing through this humus layer dissolves certain organic acids and affects the development of the lower A horizon and the B horizon. In humid tropics and subtropics, organic matter does not usually accumulate because of intense micro- and macro-biological activity.

Eluviation and Illuviation: Development of profile horizons is mainly dependent on the amount and nature of movement of water in the soil. Eluviation (meaning "wash out") is the process of removal of constituents by percolation from upper layers to lower layers. This layer of loss is called eluvial and is designated as the A horizon. The eluviated products move down and become deposited in the lower horizon which is termed as the *illuvial* (meaning "wash in") or B horizon. *Mechanical eluviation* removes finer suspended fractions of soils, producing textural profiles characterized by a coarser textured A horizon and a finer textured B horizon that sometimes develops into a hardpan. *Chemical*

Fig. 4.13 Laterisation in ages past has produced this latosol in southern India. Note the absence of horizon differentiation and the deep weathering.

eluviation differentially translocates products of decomposition such as organic matter, silicic acid, exchangeable bases, salts, hydrated alumina, and hydrated ferric oxide. The predominant constituents thus translocated determine the distinctive groups of soils produced and serves as a basis for soil classification.

Some important soil-forming processes are described as follows :

Podzolisation : It is a type of eluviation in which humus and sesquioxides become mobile, leach out from upper horizons and become

deposited in the lower horizons. Podzolisation is accelerated on sandy quartzose and base-poor parent materials under intense leaching and under forest vegetation.

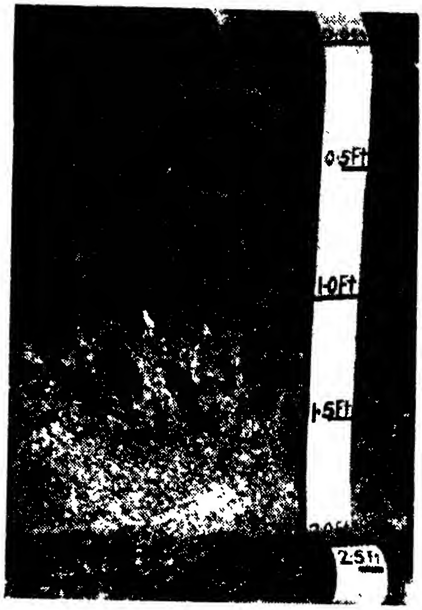
Laterisation : In this process silica is removed while iron and alumina remain behind in the upper layers and usually there are no well-defined horizons. Laterisation is favoured by rapid decomposition of parent rocks under climates with high temperature and sufficient moisture for intense leaching, such as found in the tropics. (See Figure 4.13.)

Podzolisation and laterisation produce soils that belong to the *pedalfer* (iron accumulating) group.

Calcification : In this process there is usually an accumulation of calcium carbonate in the soil profile. Such soils belong to the group called *pedocal* (calcium accumulating). (See Figure 4.14.)

Hydromorphic Profile Development : Such soil-forming processes occur under impeded drainage conditions when certain horizons become saturated and percolation is restricted. Anaerobic conditions develop and more of chemical reduction processes set in. Marsh, bog, swamp, muck and peat soils are produced.

Under fluctuating ground-water level and under monsoon climatic conditions, soils develop under alternating oxidation and reduction conditions leading to the formation of yellow, brown, or rusty mottlings.



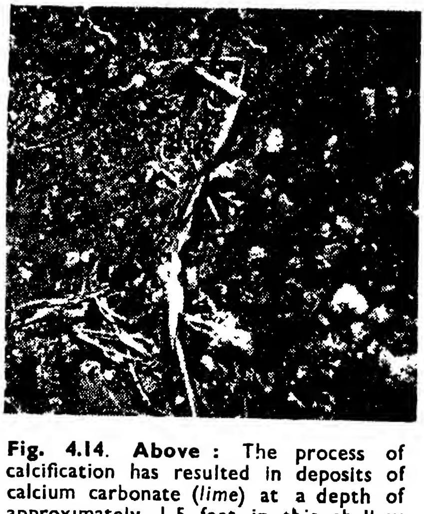


Fig. 4.14. Above : The process of calcification has resulted in deposits of calcium carbonate (*lime*) at a depth of approximately 1 5 feet in this shallow black clay soil in the 25-inch rainfall belt in Central India.
Below : The calcification process of soil formation resulted in the downward movement of calcium carbonate and shallow precipitation as nodules.
Later, because of slope of the land, erosion took away the top soil, leaving the lime nodules on the surface (*some nodules are indicated by arrows*).

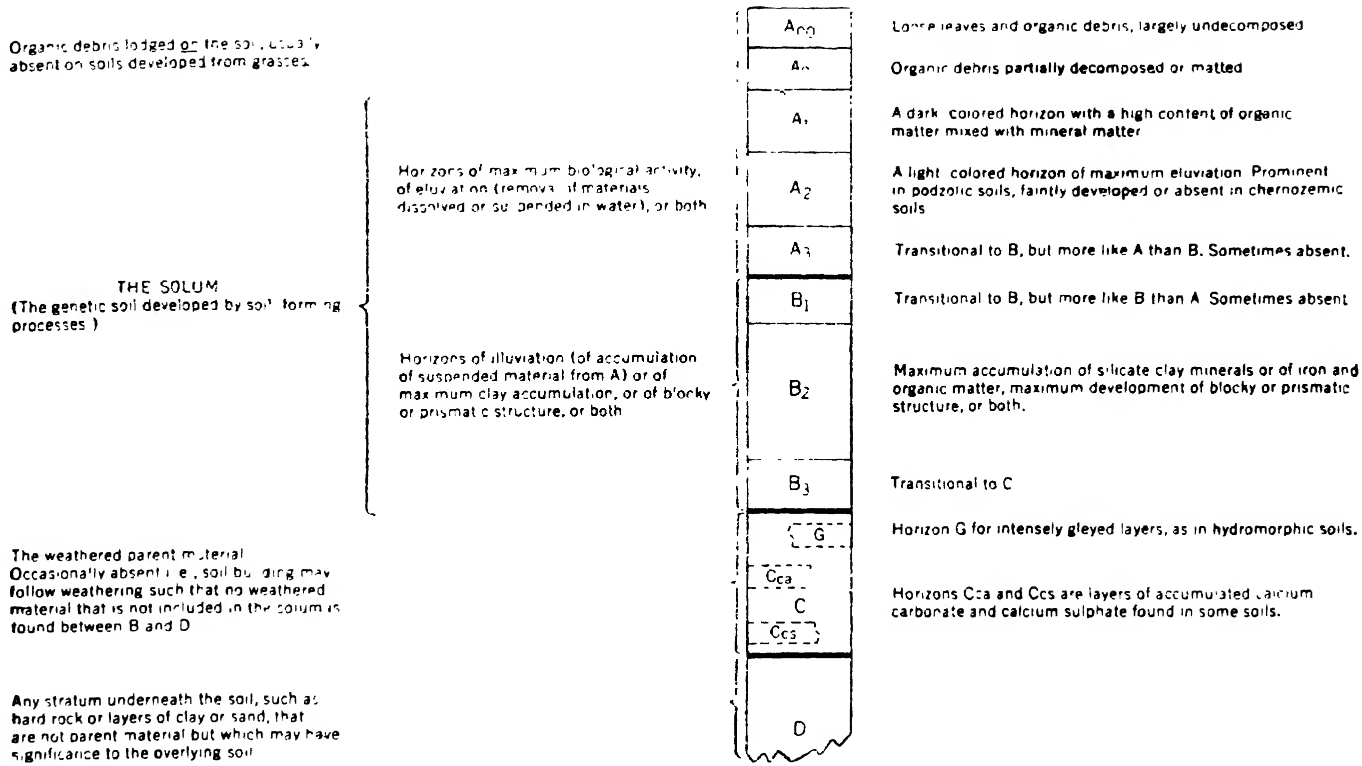


Fig. 4.15. A hypothetical soil profile having all principal horizons. It will be noted that horizon B may or may not have any accumulation of clay. Horizons Cca usually appear between B_3 and C. The G may appear directly beneath the A. (*Courtesy U.S. Soil Conservation Service*)

Under tropical conditions, sometimes the B horizon develops into concretionary '*murram*'.

22. SOIL PROFILE

A vertical section through a soil is called a profile. It represents succession of horizons differentiated from one another but genetically related to and including the parent material. The profile is divided into three broad horizons called A, B, and C. Depending upon further variations within these horizons, they are further designated as Aoo, Ao, A_1, Ap, B_1, B_{22}, and Cca. The various organic layers lying above the surface mineral horizon also form a part of the soil profile. Both A and B horizons collectively are called *solum*. Solum plus parent material is sometimes referred to as *regolith*. The parent rock lying below the parent material is termed as bedrock or D horizon.

A soil profile is an historic record of all the soil forming processes and it forms the unit of study in pedological investigations. In fact, the soil profile is the key in soil classification and also forms the basis for practical use in the utilitarian studies of soils.

A hypothetical profile including all the possible horizons is given in Figure 4.15. However, in nature no profile occurs which has all of these horizons. No two profiles are exactly alike. In fact they vary in endless ways and only a detailed description of the horizons of a profile can lead to a proper understanding and consistent grouping of the soils. A master profile or modal profile represents the central concept of characteristic horizons of a recognized kind of soil, such as the profiles of podzol, Grumusol, or Latosol.

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CHAPTER FIVE

SOIL CLASSIFICATION AND SOIL SURVEY

"What is a soil survey ? . . . An institution devoted to the study of the soil in its natural habitat. It is concerned primarily with the determination of soil characteristics ... that constitute a soil individual, the fixing of these (soil) groups by a proper nomenclature, and the determination of the area and distribution (mapping) of each soil unit."

"Soil surveys have created a new branch of soil science—soil anatomy."

—C. F. MARBUT, 1921

"Black soil for gingelly (sesamum) and stony soil for gram."

—ANCIENT TAMIL PROVERB.

Soils are one of the greatest basic natural resources of any nation. Their best utilization depends upon the knowledge and the rational application of that knowledge concerning the nature, properties, extent, and location of soils. The chief aim of soil classification and soil survey is to study and map soils of an area so that the most intelligent use can be made of them.

I. SOIL CLASSIFICATION

Soils are as diverse as the landscape of the world and vary much over the face of the earth. It is necessary, therefore, to classify them in a

systematic and orderly arrangement based upon their differences and resemblances. The details and exactness of soil classification depend upon the extent of knowledge about the soils. Thus, soil classification is essentially dynamic in nature and keeps on changing and adjusting as knowledge and understanding of the soil increases.

Soils have been classified since olden times. In India, the earliest systems, even now in vogue, are the different revenue classifications in various parts of the country. The scientific systems of classification of soils are of a very recent origin and were developed mainly in Russia and in the United States of America.

The modern classification systems are based upon the study of the soil profile which is the ultimate product and reflection of all the soil-forming factors and processes. The soils are classified into well-defined categories indicating different levels of classification. The higher categories are *order, suborder, great soil group,* and *subgroup.* They give a general understanding of the soils over large areas, indicating their world-wide relationships. The lower categories are *families, series, types* and *phases*, and are more important in recognising local differences and assessing productive capacities of soil for utilitarian purposes.

At the *order* level, the soils are classified into *zonal, intrazonal* and *azonal* groups. *Zonal* soils have developed on well-drained parent materials, and their well-developed profiles are in equilibrium with the environment, e.g., podzols, laterites, and grumusols. *Intrazonal* soils have a distinct profile and their characteristics are more influenced by local conditions of relief or parent material than by the normal effects of climate and vegetation. Usually such soils are found intermingled in small areas with those of two or more zonal groups, e.g., saline-alkali soils, ground water laterites, and rendzina soils. *Azonal* soils are without a well-developed profile owing to their extreme youth or immaturity, or to conditions of parent material or slope that prevent normal soil formation. Such soils are found on steep, rocky slopes, on fresh alluvial deposits, and on coarse sands. Azonal soils may be found in any climatic region. Lithosols, alluvial soils, and dry sands are some of the examples.

The soils are further subdivided into subsequent categories on the basis of certain major soil characteristics. (See Figure 5.1.)

Many soil scientists agree that the classification systems that have been developed mainly in temperate climates may not be fully applicable to the soils developed under tropical and subtropical climates. It has also been observed that in classifying tropical soils, there is a lack of universally accepted terminology and nomenclature for the description of soils.

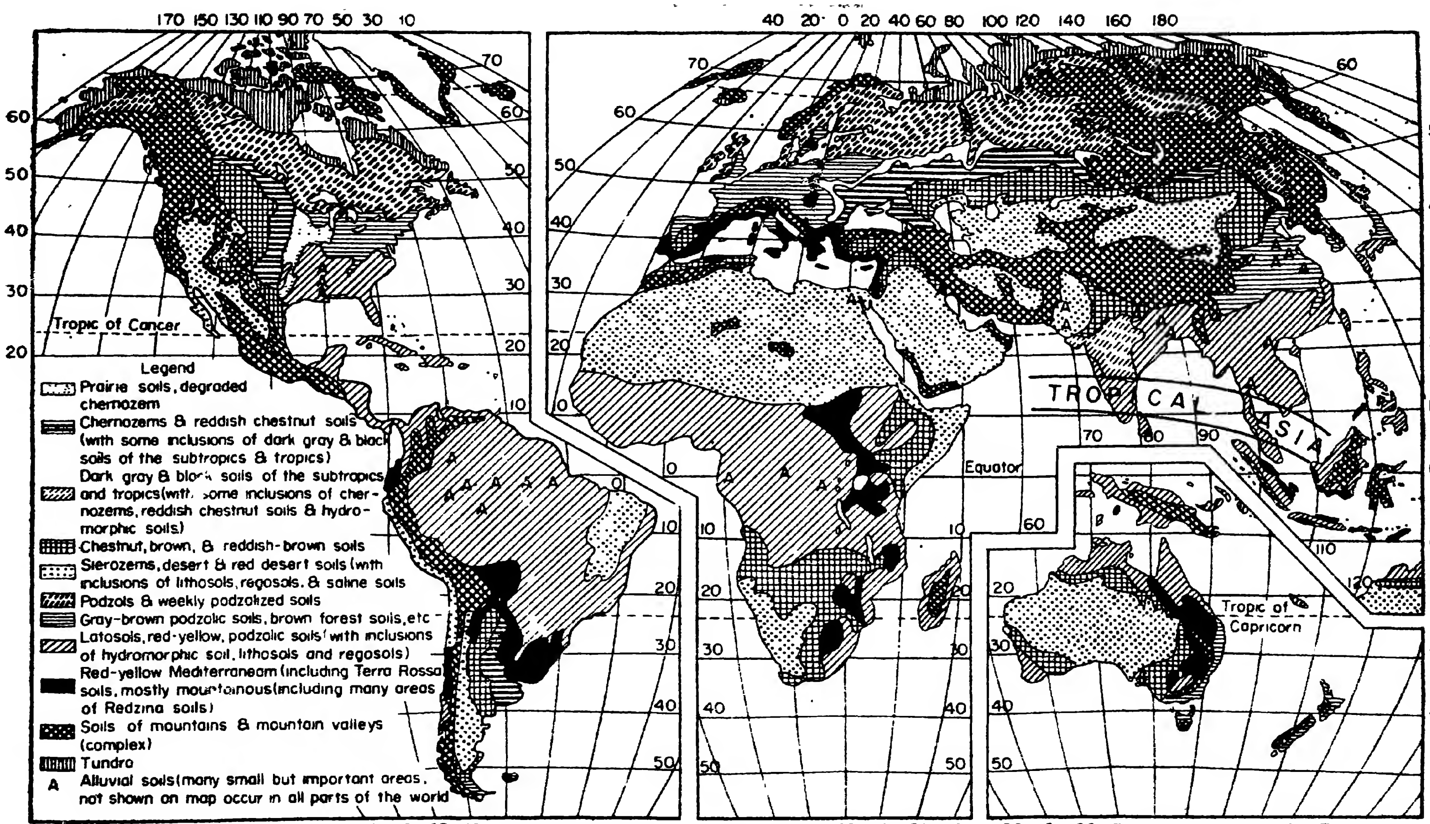

Fig. 5.1 World soil map with Tropical Asia indicated. *(Courtesy United States Department of Agriculture and Food and Agriculture Organization of the United Nations.)*

Based upon the information made available from various tropical countries, Middelburg suggested in 1950, a tentative scheme for classification of tropical and subtropical soils; this scheme is given (in Table 5.1.)

TABLE 5.1

TENTATIVE SCHEME FOR CLASSIFICATION OF TROPICAL AND SUBTROPICAL SOILS

Order	*Suborder*	*Great Soil Group*	
ZONAL	Humid Region	1a. Podzolic yellow soils with black humic top soils	
		1b. Red yellow podzolic soil	
		2. Non-laterised red soils	
		3. Laterised red soils	
		4. Degraded grey and black clay soils	Catenary association
		5. Illuvial grey and black clay soils	
	Arid Region	6. Red desert soils	—Do—
		7. Dark desert soils	
INTRAZONAL	Calcimorphic	8. Red calcareous soils over limestone	—Do—
		9. Black calcareous soils over limestone	
		10. Red calcareous soils over marls	—Do—
		11. Black calcareous soils over marls	
	Halomorphic	12. Saline soils	
	Hydromorphic	13. Ground water lateritic soils	
		14. Planosols	
		15. Organic soils	
AZONAL		16. Lithosols	
		17. Regosols (ash, loess, dry sands)	
		18. Alluvial soils	

*Middelburg H.A., *Tentative Scheme for Classification of Tropical and Subtropical Soils*. Transactions 4th International Congress Soil Science; part 4. 139—147: 1950.

In Tropical Asia, scientific studies on soils had been undertaken for many years in India, Ceylon, Indonesia, and Thailand, and useful knowledge about the soils of these countries is available. Recently some soil surveys and soil studies have been undertaken in Cambodia, Vietnam,

Philippines, Malayasia, and Taiwan, in co-operation with the F.A.O. and the U.S.A. Some of the important soil groups of Tropical Asian countries have been described.

2. IMPORTANT SOIL GROUPS

Alluvial : Alluvial soils are derived from water-deposited sediments and do not show prominent horizon development. These soils vary greatly in their physical and chemical properties as the sediments from which they are developed differ considerably, depending upon the parent materials in their respective catchment areas and the places of their deposition in the valleys. Drainage conditions also create many variations. Mostly these soils are poorly drained and have a greyish colour with mottlings. Most of these soils are acidic, excepting those in drier areas, where they often develop into saline and alkali soils. In many of the alluvial soils in India and in other Tropical Asian countries calcareous concretions have developed in the profile. Soils developed on older alluvium generally show some development of profile characteristics. An alluvial soil profile from India is described as follows :

A Profile of Alluvial Soil from Indo-Gangetic Plains, India.

Location : Village Nilwal, Delhi State, in uncultivated land under thorny scrub and grass vegetation. The area is fairly level, somewhat poorly drained, with slow permeability. The average annual precipitation is 26 inches.

Profile description :

(1) 0—4″ Light yellowish brown (10 YR 6/4) sandy loam, weakly granular with some weak lamination, loose and soft when dry, no effervescence with dilute HCl, pH 7.7.

(2) 4″—14″ Dark yellowish brown (10 YR 4/4) clay loam, somewhat crumby to subangular blocky, very hard when dry, no effervescence, pH 8.5.

(3) 14″—30″ Dark yellowish brown (10 YR 4/4) clay loam, sub-angular blocky, very hard when dry, slight localized effervescence on small calcareous concretions, pH 8.9.

(4) 30″—50″ Yellowish brown (10 YR 5/4) clay loam, blocky, very hard when dry, calcareous concretions increase in size and quantity, localized effervescence, pH 9.2.

(5) 50″—74″ Yellowish brown (10 YR 5/4) clay loam, same as above, pH 9.5.

Alluvial soils are present in all of the Tropical Asian countries in river basins, on flood terraces, flood plains and deltas. They are found extensively within India and Pakistan, particularly in the Indo-Gangetic Plains. They are further subdivided into many groups such as soils on recent alluvium and soils on old alluvium, coastal and deltaic alluvium, and lacustrine alluvium.

Alluvial soils are agriculturally very important. They are usually planted to rice in most of the Tropical Asian countries. In India and Pakistan, wheat and other crops are also grown in the central and western parts of the Indo-Gangetic Plains where a colder climate persists for a longer time.

Regosols : These soils also do not have a well developed profile but are derived from unconsolidated materials other than alluvium, such as volcanic ash, marls, and sand dunes. Their characteristics are mainly influenced by the parent material. Like alluvial soils, they also have developed under a variety of climates.

Regosols on sands are found mainly in the coastal areas of Tropical Asian countries and also in desert areas of India and Pakistan. On slope colluvium (gravity-deposition), they are found in all hilly and drier areas. On volcanic ash they are found in most of the islands of the Indonesian Archipelago and the Philippines. Regosols are not agriculturally very important, but in coastal areas, they are used extensively for coconut.

Lithosols : These are very shallow soils consisting largely of an imperfectly weathered mass of rock. They are found especially on steep slopes where little or no true parent material for soil has accumulated. The characteristics of lithosols are essentially those of the underlying rocks.

Andosols : So far the andosols have been found only on volcanic ash under humid conditions in mountainous areas of Indonesia and the Philippines. Other names for such soils are *mountain black earths*, *humic mountain soils* and *high mountain soils*. They are of medium depth, having a distinct thick black surface layer of medium to coarse texture and a crumb structure. A gritty coarse-textured hardpan often develops in a lower horizon. They are acid in reaction and are fairly well supplied with nutrients. Andosols are found mostly under forests. In some areas, cinchona, coffee, irrigated rice, oil palm, and tobacco are grown.

Podzol Soils : Earlier podzol soils were considered to be characteristic only of humid temperate regions. It is now recognized that podzol soils can be developed in tropical regions also. Podzol derives its name from the Russian root word *Zola* meaning *ash*, that resembles the distinguishing bleached ash grey A_2 horizon of podzols. In some of the Tropical

Asian countries podzols have been observed on acid coarse textured parent materials and acid volcanic tuffs under humid tropical climates with rainfalls usually above 80 inches and without a distinct dry season. They are found in coastal areas as well as at higher altitudes.

Podzol soils have a raw organic matter layer over a light grey, strongly leached sandy horizon which grades into a dark brown to reddish accumulation horizon of iron oxide and organic matter. This is an iron humus B horizon. In Tropical Asian countries, humus podzols, where organic matter accumulation is prominent, are found more extensively. Humus podzols usually develop under the influence of a high ground-water table and are equivalent to *ground-water podzols.*

Podzol soils are highly acidic and are mostly coarse in texture. They are not very important agriculturally, being mainly under forests. In Indonesia, podzol soils are locally called '*Padang*' or '*Kerangas*'. In India, podzol soils are not very common but may occur in some parts of the Himalayan mountains at high altitudes.

Red-Yellow Podzolic Soils : These soils have a textural B horizon of red to yellow colour without signs of wetness, and develop under similar but slightly drier climatic conditions than those for podzol soils. These soils have also been described as lateritic red loams and sometimes ground-water laterites. Red-Yellow Podzolic soils are of common occurrence in most of the Tropical Asian countries, especially in Vietnam, Cambodia, Taiwan, Indonesia, Ceylon, and Malaysia. Mostly these soils are under forests. In wetter zones, plantations are common. A Red-Yellow Podzolic soil profile from Cambodia is described below :

A Profile of Red-Yellow Podzolic Soil from Cambodia

Location : In a fresh road cut near Krakor in Pursat Province, developing over colluvial parent material from granite. The slope is 3-5 per cent. Drainage and permeability are good. Vegetation is a poor type of open forest with short bamboo grasses. The climate is subhumid with alternating wet and dry seasons.

Profile description :

A_1	0—6″	Grey (10 YR 6/1) loamy sand, weak medium subangular blocky, slightly hard when dry, friable when moist, pH 5.6, gradual wavy lower boundary transition to—
A_2	6″—14″	Light grey (10 YR 7/2) loamy sand, weak medium subangular blocky, slightly hard when dry, very friable when moist, pH 5.8, with gradual wavy boundary transition to—
B_1	14″—36″	Reddish yellow (5 YR 6/8) sandy loam, weak medium subangular blocky, hard when dry, friable when moist,

pH 4.2, few ferruginous concretions, with a gradual wavy lower boundary transition to—

B_2 36″—over 80″ Light red (2.5 YR 6/8) variegated sandy loam (slightly more clayey than B_1), weak medium to coarse subangular blocky, slightly hard when dry, friable when moist, pH 4.0.

Grey Podzolic Soils : They have a weak textural B horizon without much wetness. They usually contain laterite in the form of concretions or in a layer at varying depths. Most of the grey podzol soils are found on transported materials on old alluvial terraces under monsoonic wet-dry climate. They occur in most of the Tropical Asian countries.

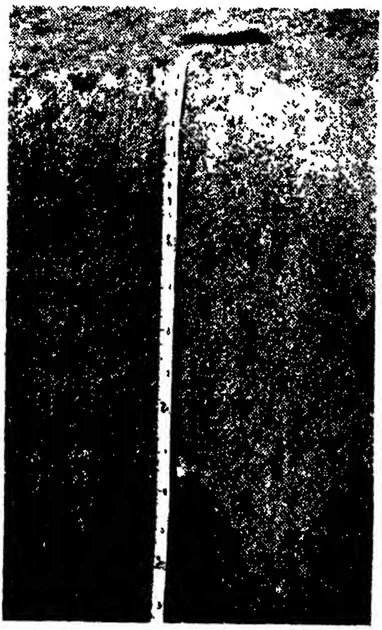

Fig. 5.2 A latosol soil profile developing from pink shales The surface 6 inches is a sandy loam soil mixed with ferruginous concretions. The next layer from 6 to 30 inches is pink shale. (Location : Raipur, Madhya Pradesh, India ; named as *Ladholi* series.)

Latosols : Latosols include most of those soils which were earlier grouped under lateritic soils. The term 'Latosol' was suggested by Kellogg* in 1949 as lateritic soils was too wide a term. The latosols are now defined to include all those soils in tropical and equatorial regions which are deeply weathered, strongly leached, and without any clear horizon differentiation. Their dominant characteristics are : a relatively low organic matter content, low clay activity, low content of primary minerals, high degree of aggregate stability, and an accumulation of sesquioxides and leaching of silica, giving a low silica/sesquioxide ratio of the clay fraction. Latosols usually develop from basic parent materials such as basaltdia,base,diorite, and andesite. The colour may vary from red to brown to yellow, depending on the nature of parent material, climate, elevation, and age of soil (Figure 5.2). Under certain poorly drained

* Kellogg, C.E., *Preliminary Suggestions for the Classification and Nomenclature of Great Soil Groups in Tropical and Equatorial Regions.* Commonwealth Bureau of Soil Science, Tech. Communication 46. 76-84. 1949.

conditions, the colour is more yellow and such soils are sometimes associated with ground-water laterites. Robinson* has suggested the term 'ferrallite' for lateritic soils. (See Figure 5.3.)

Latosols are mostly acidic. Although they are low in fertility, these soils are agriculturally very important due to their good physical conditions and resistance to erosion. They produce a variety of crops. These soils occur extensively in most of the Tropical Asian countries, especially in Taiwan and India. A latosolic soil profile from India is as follows :

A Profile of Latosolic Soil from India

Location : Village Gatapar, Raipur District, Madhya Pradesh, situated in a gently sloping upland area under little grass vegetation. Surface drainage is rapid and erosion is severe. Average annual rainfall is 52 inches.

Profile description

(1)	0—9″	Reddish brown (5 YR 4/4) gravelly silt loam, weak medium subangular blocky, hard when dry, many iron concretions, rapidly permeable, pH 6.8.
(2)	9″—23″	Brown (7.5 YR 5/4) gravelly clay loam, structure indistinct

*Robinson G. W. *Soils their Origin, Constitution and Classification.* Thomas Murby and Co., London, Third Edition, 1949.

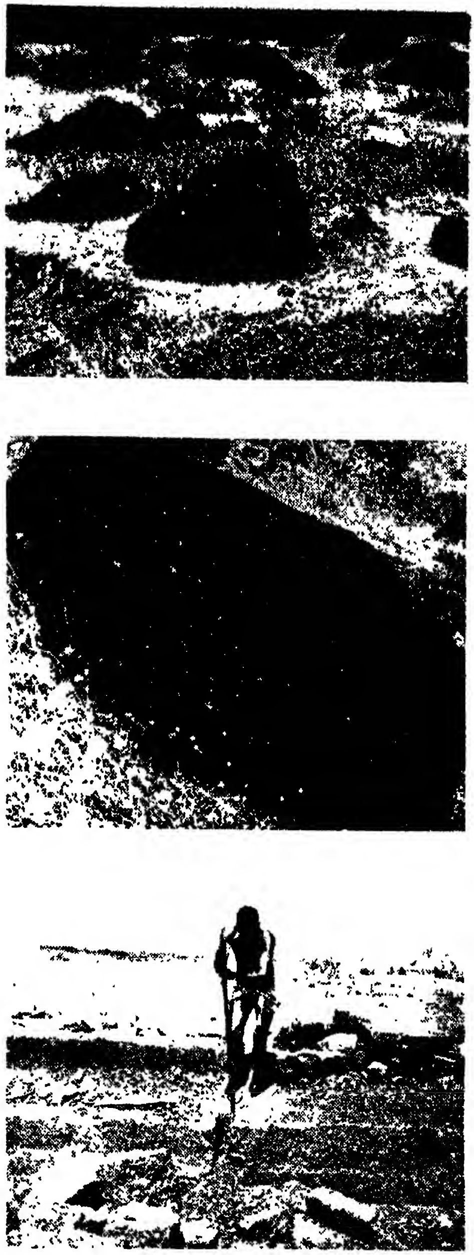

Fig. 5.3 Buried laterite material is usually yellow, but turns dark red when exposed to the air. Its structure is vesicular and somewhat similar to a honeycomb
Top : A 3-foot cap of laterite now 200 feet above the valley floor, is disintegrating.
Centre : A close-up of a laterite boulder, about 3 feet thick
Bottom : Laterite material being chiselled out to be used as building stone. (India)

due to abundance of iron concretions, fairly permeable, pH 6.7.

(3) 23″—35″ Reddish brown (5 YR 4/3) gravelly clay loam, mixed with iron concretions, fairly permeable, pH 5.9.

(4) 35″—43″ Red (2.5 YR 4/6) compact layer of iron concretions.

The term 'laterite' was first used by Buchanan* (1807) for an indurated clay of brick red colour, rich in iron material, and found in parts of south India. This material, when excluded from air, is quite soft, but on exposure to air, it soon becomes very hard. The material is often quarried for building purposes in many Tropical Asian countries. The soil has typical vesicular, honeycomb-like structure. (See Figure 5.3.)

Grumusols : These include dark clay soils of warm regions which have been variously named as black cotton soils (India), regurs (India, Cambodia, Indonesia), margalites and black earths (Indonesia), and rendzinas (Russia and the U.S.A.). In certain respects, like colour, they resemble the chernozem soils of temperate regions. In India, black soils have been subdivided on the criterion of depth into *very deep* (more than 36 inches), *deep* (18 to 36 inches), *moderately deep* (9 to 18 inches), *shallow* (3 to 9 inches), and *very shallow* (less than 3 inches). (See Figure 5.4.)

Grumusols have mainly developed from a variety of basic parent materials under alternating wet-dry climates. In basaltic regions, shallow grumusol may become very stony, but in riverine areas they are very deep. Grumusols are extensively met with in India and Indonesia. They are also found in patches in many other countries in Tropical Asia.

Grumusols have a thick dark brown to black surface horizon relatively poor in organic matter. They are high in clay content which remains usually uniform throughout the profile. Clays mostly belong to montmorillonitic group. The subsurface has a well-developed blocky structure. In India, due to the presence of slanting cleavages, the structure is sometimes termed as 'lentil'. These soils are sticky and plastic when wet. They show strong swelling and shrinkage with changes in moisture and produce wide and deep cracks. 'Gilgai', representing shallow pits and mounds in otherwise level areas, is characteristic microrelief of grumusols. Calcium carbonate is often present in deeper horizons. Grumusols are highly base saturated, mainly with calcium and magnesium cations. They are mostly neutral to mildly alkaline in reaction. A profile of margalite soil from Indonesia is described as follows :

* Buchanan, H.F. *Journey from Madras, Canara and Malabar*. London, 1807, (Quoted from Fox, C.S. Records Geol. Surv. India 69389, 1936)

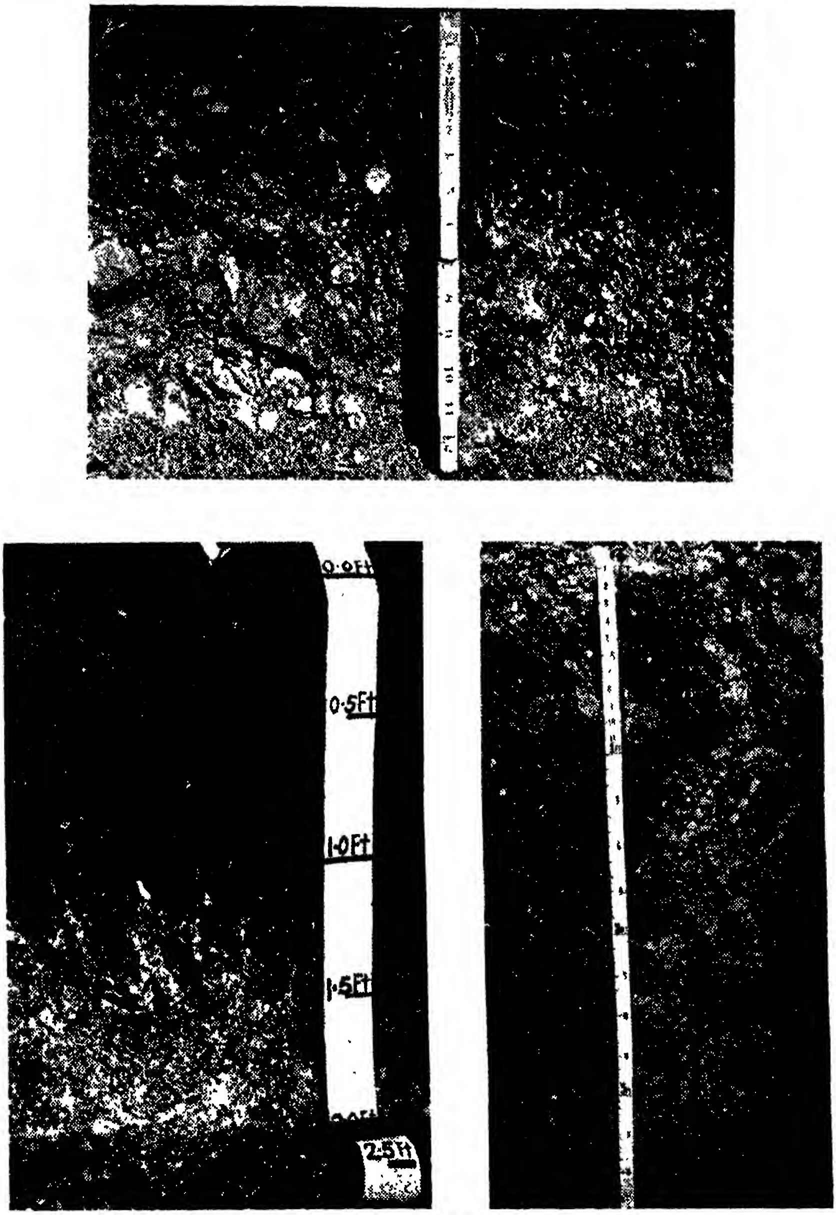

Fig. 5.4 In India grumusols (black cotton soils are usually classified into shallow, medium and deep, as illustrated in the top, bottom left and bottom right photos, respectively.

The surface soil has well-developed coarse angular blocky structure. (*All photos were taken in Central India.*)

Fig. 5.5 Characteristic 'gilgai' micro-relief representing a succession of micro-basins and micro-knolls in nearly level areas. In grumusols, gilgai micro-relief is common

Profile of Margalite Soil (Grey Andesitic) from Indonesia

Situation : Level to undulating terrains at the foot of Lawu, generally underlain by more or less indurated gravelly tuff.

Profile Description :

(1)	0—16″	Dark grey (10 YR 4/1 dry) clay, angular blocky, some pea-sized round iron concretions, grading into—
(2)	16″—28″	Grey (10 YR 5/1 dry) clay, blocky, grading into—
(3)	28″—48″	Greyish brown (10 YR 5/2 dry), grey veined clay containing many vertical veins of lime, rapidly grading into—
(4)	48″+	Weathered sandy tuff "padas" with veins of lime.

The dark colour of these soils is not due to their high organic matter content ; in fact they are low in organic matter. The investigations in India show that the black colour may be due to presence of titaniferrous magnetite compounds and or clay-humus complexes.

Agriculturally, grumusols are very important because a variety of crops are grown on them, such as cotton, *jowar*, and tobacco. Their clayey nature makes them problematic for efficient agricultural management, such as tillage at the proper moisture content, and their high susceptibility to erosion. (See Figure 5.5.)

Non-Calcic Brown Soils and Red-Brown Earths : These soils include nonlateritic brown soils, nonlateritic red loams, terra rossa, and possibly the red loams and red earths of India. They usually develop under

monsoonic-medium dry climates. Noncalcic brown soils are derived from acid to intermediate (near neutral) parent materials. Red brown earths develop on parent materials fairly high in ferro-magnesium minerals, and sometimes on basalts and limestones. Both soils show a textural B horizon. They occur in some parts of Ceylon, Indonesia, Burma, Cambodia, Thailand, and Vietnam. Lack of water sometimes restricts their use for agricultural purposes. They are good for grassland development. Red loams of India are mostly argillaceous, blocky with a structure, and red earths have a friable top-soil with secondary concretions.

Grey Hydromorphic Soils : These soils, also known as low humic gley, are found on transported materials in poorly drained depressions having a fluctuating high ground-water table. They show dominant wetness, and gleying throughout the profile. These soils have a thin surface horizon and a textural B horizon, usually mottled with brownish grey to olive grey colours. On drying, these mottles sometimes turn into lateritic concretions. These soils occur in patches in most of the Tropical Asian countries. Rice is the most important crop. Plinthite hydromorphics and brown hydromorphics are also recognized in Cambodia.

Desert Soils : They have developed in arid regions mostly under the influence of physical weathering, and are mainly sandy or sand dunes. The soils are light in colour and relatively unleached. Both water and wind erosion are severe. Desert pavements of stony layers are commonly formed where wind erosion is prominent. Often a surface crust develops which is relatively impermeable to water. Shifting or partially established sand dunes are common. Soils which have developed on smooth alluvial fans and along broad stream valleys are often suitable for farming if irrigation water is made available. Such soils are found in desert areas of India and Pakistan.

Organic Soils : These soils originate under humid climates as a result of accumulation of organic matter. Organic soils have a relatively thick organic surface layer. They are poorly drained and have a high ground-water table almost throughout the year.

Organic soils represent bog, half-bog, peaty, marshy, and swampy soils. They occur in coastal marshes or in inland swamps and in various depressions in mountain areas. They are extensively found in Indonesia, Sarawak, and in small patches in Malaysia, Ceylon, Vietnam, the Philippines, and India. They are of little agricultural value unless reclaimed and well-managed. Rice is grown in many cases, but mainly they are under forests.

Paddy Soils : Paddy soils by themselves do not represent a great soil group, but refer to the soils of other groups where rice is grown under submerged conditions. Tropical Asia constitutes the major rice-growing region of the world and paddy soils assume a great importance and require more studies. In Cambodia such soils have been referred to as cultural hydromorphics.

Under the artificial flooding necessary for rice culture, certain changes especially in the surface horizon are created, such as the formation of a plough pan consequent to puddling ; formation of surface gley ; and the downward translocation of iron and manganese from the surface layer. Modifications in the surface soils are also caused by terracing and bunding of rice fields. (See Figure 5.6.)

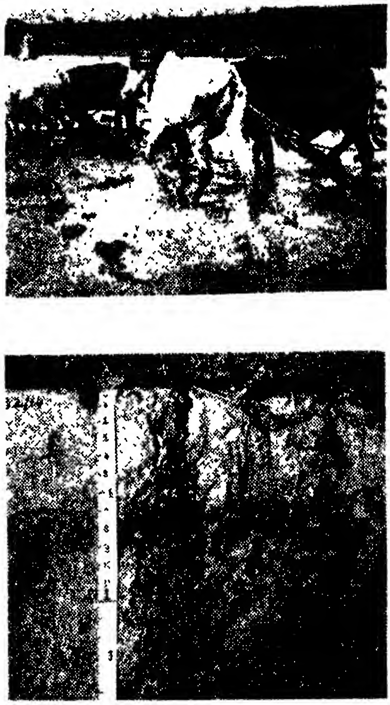

Fig. 5.6 Above : The continuous puddling of the soil for one, two, or even three rice crops a year ; by the trampling action of the feet of bullocks and buffalo ; together with the compaction caused by running the *desi* plow at the same depth, have resulted in :
Below : A rice soil profile that shows a dark compacted horizon between 6 and 11 inches in depth.

3. SOIL CLASSIFICATION – 7th APPROXIMATION

The Soil Survey Staff of the United States Department of Agriculture has proposed a new natural soil classification system called "Soil Classification—A Comprehensive System—7th Approximation, 1960". Efforts have been made in India, and in some other Tropical Asian countries to test this system for adoption and modification, if any, under the local conditions.

The 7th Approximation lays more stress on the morphology of soils themselves rather than on the environmental factors. The classification also has an agricultural bias at the level of lower categories. The system classifies the soils into several categories as orders, suborders, great groups, subgroups, families, series, and types. The details of differentiation and the nomenclature for different categories have been developed up to the level of great groups. The nomenclature used consists of coined terminology derived from root words from many languages. The coined names as such

are suggestive of the category level of classification and are also indicative of some more important properties of that category. For example, the name *Aridisols* indicates the 'order' category and suggests dry conditions and includes soils of deserts.

Ten orders have been suggested based mainly on common properties of soils that lead to similar horizon differentiation. They are Entisols, Vertisols, Inceptisols, Aridisols, Mollisols, Spodosols, Alfisols, Ultisols, Oxisols, and Histosols. The eqivalent soil groups described for Tropical Asian regions under different orders are approximately as follows:

Order	*Soil Group of Tropical Asian Region*
Entisols	Alluvial soils, Regosols.
Vertisols	Grumusols.
Inceptisols	Andosols.
Spodosols	Podzols.
Alfisols, Ultisols	Non-clacic brown soils, Red brown earths, Grey hydromorphic soils, Red yellow podzolic soils, Grey podzolic soils.
Oxisols	Latosols.
Histosols	Organic soils.
Aridisols	Desert soils.

4. SOIL SURVEY

A soil survey is essentially a study and mapping of the soils in the field in their natural environments. It is a purposeful research of both fundamental and utilitarian nature. It is fundamental as it helps to recognize different soils, define their important characteristics, and provide material for soil correlation and classification. Soil survey is utilitarian as it provides soil maps delineating the basal soil pattern of an area, and furnishes basic data for making interpretations and predictions as to the adaptability of the soils especially for agriculture but also for many other purposes. Soil surveys provide a workable link to extend the useful results of agricultural research to the land.

Soil surveys are most important for any nation to provide an inventory and stock-taking of the national soil resources in order that public policies may be more wisely made and executed

Types of Soil Surveys: Depending upon the prospective use of soil surveys and details with which soil boundaries are demarcated, the following three types of soil surveys are recognized :

1. *Detailed Surveys:* Elaborate mapping is done, demarcating the lowest categories of taxonomic and mapping units, *viz.*, types and phases—which are genetically quite homogeneous. For cartographic details, large-scale base maps and fairly large-scale publication maps are essential. Detailed surveys are always most time-consuming. The field traverses and observations are made in greater details. Such surveys are most useful especially in areas of intensive use and provide sufficient information for interpretations of various kinds and uses.

2. *Reconnaissance Surveys:* The mapping is less elaborate and the soil units delineated are of a higher category such as well defined complexes like *associations*. Small-scale base maps are used, the field traverses are made at wider intervals, and larger areas are surveyed rapidly. Such surveys provide broad understanding of soils and are particularly useful in new and relatively undeveloped regions for general planning. Reconnaissance surveys fairly serve the purpose in areas of lesser importance such as in mountainous regions.

3. *Detailed-Reconnaissance Surveys:* They constitute elements of both detailed and reconnaissance surveys. The regions of better use potentialities are surveyed in detail while reconnaissance surveys are made in regions of low potentialities.

5. SOIL SURVEY METHODS

Soil surveys can be useful for many purposes, but the soil survey methods are basically the same for any kind of prospective use. They primarily concern the studying of soil profiles in the field as well as in the laboratory; traversing and studying soil borings at required intervals; mapping soils according to well-defined legends; collecting all relevant information about the climate, physiography, hydrology, geology, vegetation, present land use; scientific data about recommended practices and their responses; socio-economic conditions of the area; and preparing soil survey reports and soil maps. To suit local conditions, the details of methods are somewhat modified in different countries. Elaborate survey methods have been developed in the United States of America. Manuals for soil studies in the field have also been compiled in England, New Zealand, and India. (See Figure 5.7.)

To undertake a soil survey of any area, the first requisite is collection of all available information and records on soils and allied aspects, procurement of base maps and preparing work plans. The most useful base maps are

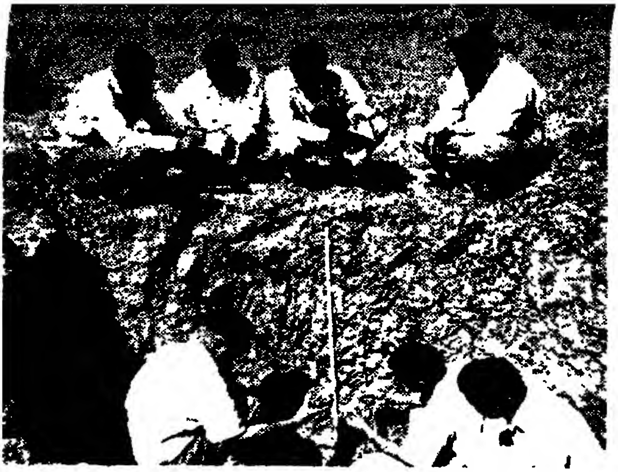

Fig. 5.7 The study of soil profile in the field is essential in soil surveys. It helps in soil classification, soil mapping, and better understanding of the soils for utilitarian purposes.

Above : Studying a soil profile in the field to a depth of five feet is essential to completely and accurately describe a particular soil type.

Below : An approximate estimation of the particular soil type can be made by boring into the soil with an auger and examining it by ocular estimation.

(Below : Courtesy Soil Conservation Service)

aerial photographs. Detailed topographic maps based on triangular surveys are also useful. The survey work begins with a preliminary inspection of the area to understand the broad soil and physiographic patterns and to plan traverses and legends. Two important aspects of soil surveys are preparing complete descriptions of mapping units and delineation of soil boundaries.

Soil Mapping Units : They are recognized through profile examinations, named within the general system of soil classification and mapped in appropriate symbols. There is a close relationship between soil mapping units and taxonomic units. In soil surveys, it is generally the lower categories of classification such as series, types, and phases that are studied, defined, and mapped. The mapping units should be very well defined (categorical details) and their extent should be accurately mappable (cartographic details).

Soil Series : A soil series represents a group of soils having horizons similar in characteristics and arrangement in a soil profile developed from a particular type of parent material, but they may differ in the surface texture. It is given a geographic name either of the locality where it is well developed or where it was first recognized; for example, Tiwsa—representing a deep black soil in India ; Guadalupe—a grumusol soil in the Philippines ; Korat—a podzolic soil in Thailand ; and Lakholi—a latosolic soil in India.

The series name is highly informative and indicates a whole picture of the soil with respect to its morphological characteristics such as topography, and drainage ; profile characteristics as to the kind, thickness and arrangement of the horizons ; colour, texture, structure, consistence, reaction, and organic matter content of each horizon ; and any special features such as mottling, concretions, pans, and soil permeability.

Soil Type : It is a subdivision of series based on the texture of the surface soil. It is named by adding the textural class name of the surface horizon to the series name, e.g., Tiwsa silty clay, Tiwsa clay, and Lakholi sandy loam.

Soil Phase : Strictly speaking, soil phase can be a subdivision of any category of soil classification, but in itself is not a category of the system. Phases in soil survey are mostly subdivisions of soil types in respect of soil slope, degree of erosion, stoniness, rockiness, and salinity. They mainly indicate differences of practical significance. An example of a phase name in Tiwsa stony clay is the word "stony", meaning "Tiwsa clay, stony phase".

In defining types and series, it is very important to indicate permissible ranges of all relevant characteristics.

Soil Complex : It is a compound mapping unit consisting of two or more soil types or series that cannot be separately mapped as they exist in small areas in an intricate pattern. It is not a category in the soil classification system. Soil complexes are named after the names of composing types or series, and the percentages occupied by each composing unit are also indicated.

Soil Association : It is fairly similar to a soil complex. *Catena* is also a complex mapping unit representing different soils developed from the same kind of parent material due to the influence of differing relief and drainage.

Special Mapping Units : These are used to map miscellaneous land types for areas of little or no natural soil, or when soil classification is not feasible. A few examples are : alluvial land, beaches, dune lands, gullied lands, marshes, swamps, rocky lands, rough broken lands, rough mountainous lands, urban lands, and fresh volcanic ash lands.

Legend: It is a list of defined mapping units with their symbols. The units in the legend should be such that they are suited to the details of the natural soil pattern and to the scale of the map and the purpose of the survey.

6. SOIL PROFILE DESCRIPTION

Soil profile—a vertical section through a soil—consists of various horizons which differ from one another in colour, texture, structure, and consistence. Soil profiles are examined in dug pits or through auger borings, down to the parent material or to a depth of 5 to 6 feet.

Both site characteristics of the profiles and specific characteristics of its horizons are recorded in detail during the soil survey. The site characteristics help to define the soil, give some indications of soil genesis, and serve as a base for future studies of any changes undergone by the site and their effects on soil properties.

It is very important that uniform standards are used in characterizing sites and profile horizons so that the descriptions are universally understood and soils of different places can be easily compared, defined, correlated, and classified. To ensure desired uniformity, standard forms are used.

Various characteristics are categorized into a number of measurable and well defined classes. The standard terminology and symbols used for various classes of the characteristics and methods of their recognition have been described in detail in the Soil Survey manuals of different countries. (See Figure 5.8.)

Fig. 5.8 Standard Proforma for Soil Profile Description.
(As followed in India)

I. Site Characteristics :

Profile No ______ Date ______ Examined by ______

Map. Ref ______ Village ______ Taluka ______

District ______ State ______

Relief ______ Elevation ______

Physiography ______ Slope with aspect ______

Geology ______ Climate ______
(Parent material)

Drainage ______ Ground water ______

Salt or alkali ______ Stoniness ______

Erosion ______

Natural vegetation ______

Present land use ______

Additional notes ______

II. Profile Characteristics :

Horizon									
	Serial No								
	Nomenclature								
Depth									
Thickness									
Boundary									
Colour	Dry								
	Moist								
Mottling									
Texture									
Structure									
Consistence	Dry								
	Moist								
	Wet								
Concretions									
Carbonates									
Reaction									
Root distribution									
Permeability									
Special features									
Bag No. if sampled									
Remarks									

(Include sketch of soil profile and direction of slope.)

Soil Mapping : Soil mapping is a technical art and requires the knowledge of geographical aspects. With the defined soil mapping units and legends available, the mapping should start and proceed along with field traversing. It is essential for the surveyor to always know his position on the map with respect to his ground position. A soil map is a map that shows the distribution of soil units in relation to the prominent landscape features such as hills and rivers.

7. LABORATORY ANALYSES FOR SOIL CHARACTERIZATIONS

The requisite laboratory analyses are an essential part of the soil survey for checking some of the field observations, for proper understanding of the soils, and for making valuable interpretations. However, the nature and amount of laboratory work to be done depends on the primary purpose of the soil survey. First of all it is essential to collect, during field work, necessary soil samples from representative profiles, auger borings, and surface horizons. Some routine determinations made on the samples include mechanical analysis, pH, carbonates, total soluble salts, organic carbon, nitrogen, exchange capacity and exchangeable bases, water holding capacity, moisture equivalent, available nutrients, and permeability. For fundamental pedological studies, selected representative samples need to be analysed for the nature of the clay, molecular ratios, and for petrographic and mineralogical analysis. For certain specific interpretations such as engineering, irrigation, and drainage aspects, certain special investigations are also necessary.

8. SOIL MONOLITHS

These are permanent records of important soil profiles. They are prepared by preserving undisturbed profile columns in suitably sized wooden or metal boxes. Often transparent gluing materials like vinyl resin are also used to preserve the monoliths in natural condition. In India the monoliths are prepared in wooden boxes mostly of 6″ × 2″ × 48″ or 60″ size. Preparation of such macromonoliths is a skillful and laborious job. Micromonoliths are more convenient and are prepared by pasting on hard board or by putting in small wooden boxes (3″ × 1.5″ × 12″), proportionate undisturbed sections of each horizon. The monoliths are useful in soil correlation studies. They are good exhibits of natural soil samples and also aid in teaching. (See Figure 5.9.)

Fig. 5.9 The Technique of Preparing Macromonoliths (India).

Top : The perfected soil column ready for fitting the box on.

Bottom : Fitting the box The next step is to carefully dislodge the column from the back side.

9. SOIL SURVEY REPORTS

The soil survey cannot be considered as complete unless a soil survey report and soil map are ready for the use of all concerned such as scientists, teachers, administrators, planners, and farmers. The reports interpret the results of research and local experiences in the form of capabilities and responses of each kind of soil to different treatments. The soil report and the soil map supplement each other for the presentation of the soil survey data. Modern reports combine both utilitarian and scientific functions of the soil surveys. The survey reports are designed primarily to serve agricultural purposes but also contain most of the information for making interpretations for other uses.

The soil survey reports are generally written to include the following :

1. Primary purpose of the survey.
2. General description of the area : location, size, physiography, drainage, geology, natural vegetation, climate, general agriculture and land use, socio-economic conditions, and problems.
3. Discussion of the soil-forming factors, classification of soil, and a description of the mapped soil units.

4. Soil-crop relationships with various kinds of interpretations, capabilities, and responses of important soil units to different levels of management, use of fertilisers, new crops, soil and water conservation treatments, irrigation, drainage, and reclamation measures.
5. Necessary and relevant tables, appendices, diagrams, photographs, and other useful information.

10. USES OF SOIL SURVEYS

Apart from the uses of soil surveys for defining, classifying, and mapping of soils ; indicating potentiality predictions for various agricultural and silvicultural managements, assessing natural soil resources and general planning, the soil surveys have also proved helpful for a variety of other purposes. They are basic to irrigation agriculture in defining and delineating irrigation suitability classes, in determining feasibilities and requirements of drainage projects, demarcating nutrient deficiency areas, locating problems like badly eroded areas, waste lands, areas damaged by floods, saline-alkali areas, and suggesting methods of their reclamation and improvement. In deteriorated areas they indicate necessary soil and water conservation treatments. They also supply basic information for watershed planning and management. Recently the application of soil surveys has also been appreciated in land settlement, rehabilitation, tax appraisal, locating and designing

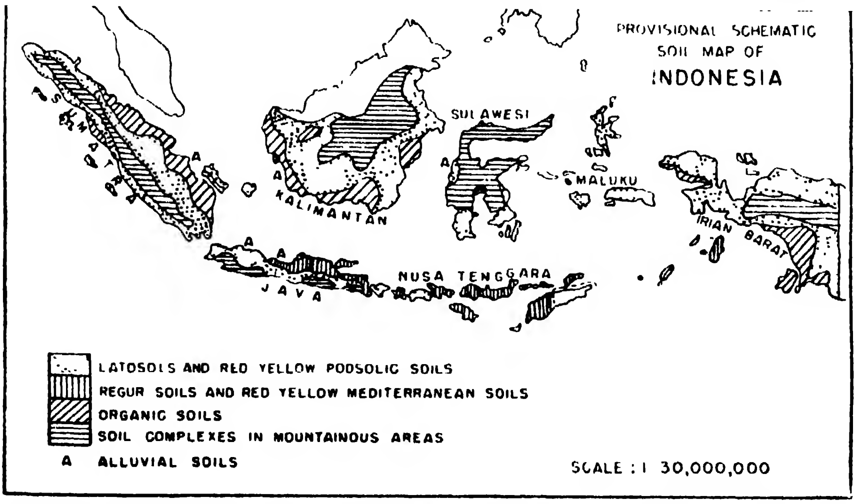

Fig. 5.10 Generalised soil map of Indonesia. *(Adapted from : Soepratohardjo, M., Soil Regions of Indonesia. Contributions of the General Agricultural Research Station, Bogor, Indonesia, No. 159, 1957.)*

highways, airports, and other engineering structures, and in public sanitation works. Thus soil surveys are helpful in finding out an effective cultural balance between people and the land. They form an important aspect in world-wide programmes for sustained food production.

II. SOIL SURVEYS IN TROPICAL ASIA

Studies on the soils in Tropical Asian countries date back to the beginning of the present century. In the earlier periods the studies were mainly

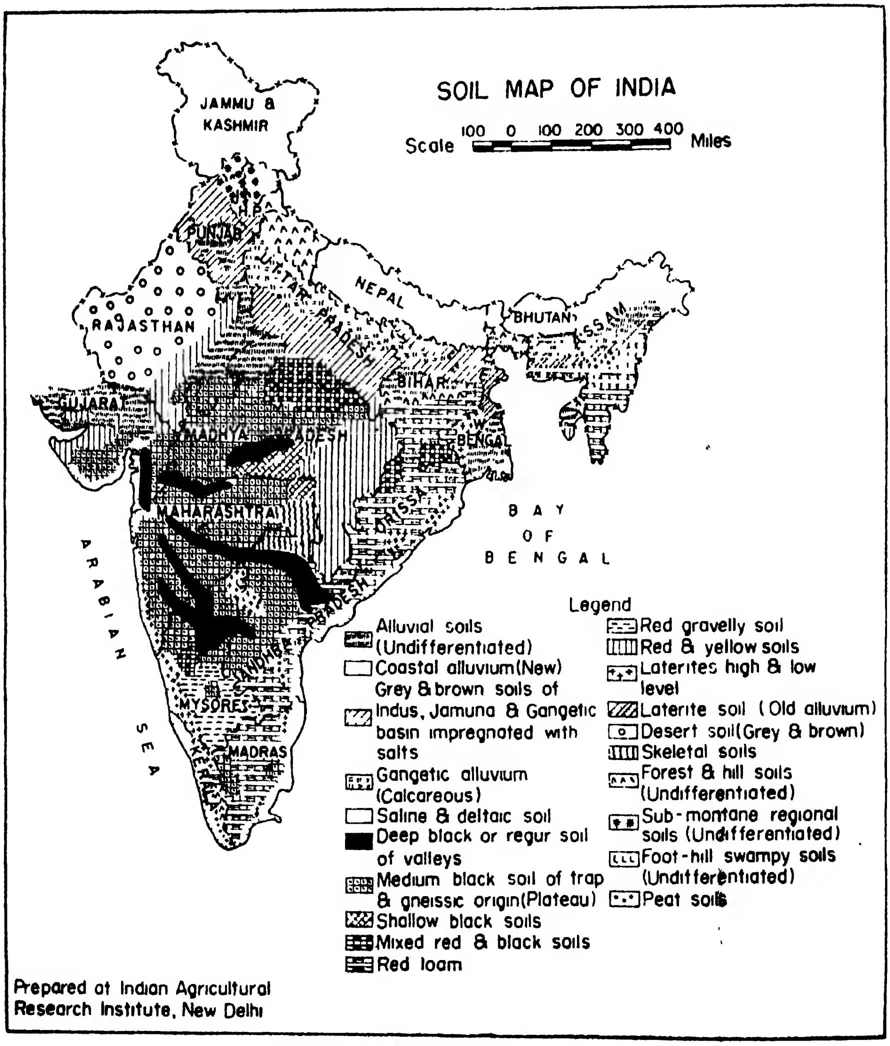

Fig 5.11 A generalised soil map of India.

confined to physico-chemical analysis of soils in a sporadic way. Although knowledge about certain important soil groups in these countries was gathered, actual soil surveys and soil mapping were started in the very recent past.

In Indonesia, Philippines, Cambodia, Thailand, Ceylon, Vietnam Taiwan, and India, reconnaissance surveys have been completed or are in progress over large areas. A schematic soil map of Indonesia has been prepared (Fig. 5.10). F.A.O. and the U.S.A. have helped many countries in their soil survey programmes. Detailed surveys are being carried out to a limited extent. In many of the Tropical Asian countries aerial photographs are used as base maps.

In India, cadestral village maps (large-scale made for revenue purposes) and Survey of India topographic sheets (1″=1 mile) are used as base maps. Efforts are being made to use aerial photographs. In India, soil surveys are being conducted in the country by Central as well as State agencies. Most of the detailed surveys are concentrated in the catchments of major river valley project areas with the main objective of providing basic soil information for soil and water conservation treatments. Pre-irrigation and post-irrigation surveys have also been made for large areas under command of big irrigation projects. A generalized soil map of India has been prepared. (See Figure 5.11.)

12. LAND CAPABILITY CLASSIFICATION

The basic soil information made available through soil surveys is related to the management of soil and can be interpreted in many ways. One such interpretative grouping is "Land Capability Classification" indicating the suitability of various kinds of soil mainly for agricultural purposes. The guiding principles for this classification are the limitations imposed on the sustained use of soils by the basic characteristics of soils in combination with climate, landscape features, erodibility, and other natural hazards. The various soil units are grouped into suitable land capability classes. This classification has been developed in the U.S.A. where it is extensively used for farm conservation planning. It has been adopted in many other countries with certain modifications. The land capability classification determines the use ceiling for any piece of land and helps to define the conservation problems and possible treatments.

The capability classification is made into three categories, namely (1) capability classes, (2) capability subclasses, and (3) capability units.

MAJOR LAND-USE SUITABILITY (Broad grouping of limitations)	LAND-CAPABILITY CLASS (Degree of limitations)	LAND-CAPABILITY SUBCLASS (Kind of limitations) (Grouping of land-capability units. Examples of possible subclasses in class III.)	LAND-CAPABILITY UNIT (Distinctive physical characteristics) (Land-management groups based on permanent physical factors. Example.)
Suited for cultivation	I — Few limitations. Wide latitude for each use. Very good land from every standpoint		
	II — Moderate limitations or risks of damage. Good land from all-around standpoint		
	III — Severe limitations or risks of damage. Regular cultivation possible if limitations are observed	Limited by hazard of water erosion: moderately sloping land	13-C-2 Moderately sloping, slightly acid soils on limestone
			9-C-2 Moderately sloping, highly acid soils on sandstone or shale
		Limited by excess water: needs drainage for cultivation	
		Limited by low moisture capacity: sandy land	
		Limited by tight, very slowly permeable subsoils: claypan land	
	IV — Very severe limitations. Suited for occasional cultivation or for some kind of limited cultivation		
Not suited for cultivation, suited for permanent vegetation	V — Not suited for cultivation because of wetness, stones, overflows, etc. Few land limitations affect grazing or forestry use	Groupings of range, pasture, or forest sites.	Land-management groups based on permanent physical factors, such as range sites or forest sites.
	VI — Too steep, stony, arid, wet, etc., for cultivation. Moderate limitations for grazing or forestry		
	VII — Very steep, rough, arid, wet, etc. Severe limitations for grazing or forestry.		
	VIII — Extremely rough, arid, swampy, etc. Not suited for cultivation, grazing, or forestry. Suited for wildlife, watersheds, or recreation		

Fig. 5.12 Outline of Land-Capability Classification (*Source: A Water Policy for the American People, Vol. I, Report of the Preeident's Water Resources Policy Commission, 1950*).

Capability Classes : Eight land capability classes are recognized and indicated by Roman numbers. Classes I--IV include lands suited for cultivation. However, they can be used for other purposes as well. Class I is the best land free of any limitations and requires ordinary good farming practices. Classes II—IV have progressively increasing hazards and limitations and require an increasing number of soil conservation measures. As the capability class increases from II to IV, the use for cultivation becomes more limited. (See Figures 5.12 and 5.13.)

Classes V—VIII are primarily not suited for cultivation and should be maintained under natural vegetation of forests or grasses. Classes V—VII have increasing hazards and limitations and proper soil conservation practices

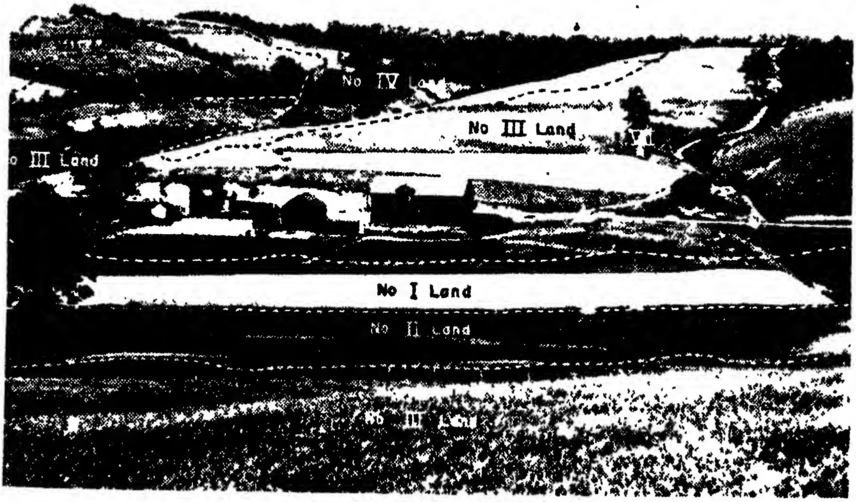

Fig. 5.13 A landscape that has been demarcated to show the Land Capability Classes indicated in Fig. 5.12 *(Courtesy Soil Conservation Service)*.

are needed for each class. Class VIII lands are mainly suited for wildlife, recreation, or watershed protection.

Capability Subclasses : These are the subdivisions of capability classes made on the basis of four dominating limitations, namely, (1) risks of erosion (e), (2) wetness, drainage or overflow (w), (3) rooting zone limitations (s), and (4) climatic limitations (c). Subclasses are mapped by adding limitation symbol to the capability class number, e.g., IIe, IIIs, etc.

Thus subclasses are indicative of both degree and kind of limitation. There are no subclasses in Class I.

Capability Units : These are further subdivisions of capability subclasses. A capability unit consists of soils which are sufficiently uniform in their characteristics, potentialities, and limitations and require fairly similar conservation treatments and management practices.

The land capability classes can change towards better classes, if the existing limitations can be permanently removed or reduced in extent by economically feasible reclamation projects or corrective measures, such as providing irrigation, installing drainage, constructing flood retarding structures, or controlling large-scale gullies. A further deterioration in existing conditions can similarly shift the capability to a poorer class.

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CHAPTER SIX

SOIL AND WATER CONSERVATION

> *" Ridges made of earth should at first be constructed for the purpose of dividing the fields and for conserving water in the fields, and then the seed should be sown."*
>
> KHANA (600 A.D)

For the growth and sustenance of life, soil and water are most essential. Soil is important as it provides the foothold and majority of nutrients needed for the growth of plants and animals. Water is necessary as it forms a larger part of the living matter and acts as the nutrient carrier. In nature, although these two resources, soil and water, are widespread and quite in abundance, yet they are not equally distributed in quality and quantity in every part of the world. The total amount of these resources available for any nation is limited. Further, both water and soil resources are exhaustible and can become easily wasted if improperly used.

The abuse of soil and water can lead only to ruin. Mohenjodaro and Harappa excavations in West Pakistan are glaring examples of old civilizations that became extinct due to the neglect of their lands. Rivers like the Sarasvati have disappeared as their watersheds and valleys were exploited and mismanaged. Such examples are found in the history of every nation all over the world. The misuse still continues and the nations are being continuingly impoverished of their important soil and water resources.

For the survival of humanity and for the economic stability of nations, conservation of soil and water resources is a prerequisite. Conservation aims at using these natural treasures to the best advantage and at the same time maintaining and enhancing their productivity continuously.

1. SOIL CONSERVATION

Soil, the thin outer mantle of the earth varying in depth from a few inches to a few feet, and more so its top 6 to 9 inches, is the real storehouse for plant growth. Nature takes centuries to produce this soil, but man may lose it in a few years due to catastrophic soil erosion. We must, therefore, save our soils against erosion because the soil once lost is difficult and expensive to replace.

2. SOIL EROSION

Soil erosion is the wearing away, detachment, and removal of soil from one place and its deposition at another through the forces of striking and moving water, blowing winds, strong waves, snow, and gravity. Under normal physical, biotic, and hydrological equilibrium in nature, the erosion that takes place is *normal*, natural, or geological, wherein soil removal is fairly balanced with soil formation processes. When this balance gets disturbed by man's exploits and by natural calamities, the soil loses its resisting power and eroding agencies become more active and cause *accelerated* erosion (Table 6.1).

TABLE 6.1

RUNOFF AND SOIL LOSS ON MEDIUM DEEP SOILS OF ABOUT 1.2% SLOPE AND AVERAGE RAINFALL OF 23.9 INCHES—SHOLAPUR, MAHARASHTRA STATE, INDIA

(Average of nine years from 1934-43)*

Land use	Runoff, of total rainfall (per cent)	Soil loss per acre (annually) (Tons)	Estimated time to erode 7 inches of top soils (years)
Natural vegetation	4.77	0.53	1852
Summer cropping	16.50	23.80	42
Winter sorghum	18.67	34.54	27

**Source*—Kanitkar, N.V., Sirur, S.S. and Gokhale, D.H., *Dry Farming in India*. Indian Council of Agricultural Research, New Delhi. 2nd Edition, 1960.

3. FACTORS AFFECTING SOIL EROSION

The factors influencing erosion are :

1. Climate, especially precipitation, and wind velocity.
2. Topography with special reference to nature, degree, and length of slope.
3. Physical and chemical characteristics of soil.
4. Ground cover, its nature and extent of coverage.

5. Natural phenomena such as earthquakes, land slides, and upheavals.

As a functional equation: Erosion=f (cl, v,t,s,h,).

Where f=function of or dependent on.

cl=climate

v=vegetation

t=topography

s=soil

h=human factors.

Precipitation is the most forceful factor causing erosion through splash and excessive run-off (Figure 6.1 and Table 6.1). Run-off may occur without erosion but there is never erosion without run-off. Run-off that causes erosion is dependent on amount, duration, intensity, and frequency of the rainfall and also the time of the season when rainfall occurs. High intensity, short duration downpours invariably cause maximum run-off. Tropical rains often occur in torrents and heavy downpours which favour more erosion and cause flash floods. Certain observations in India have shown that all rains in excess of 2 inches per day always cause run-off, whereas those below ½″ cause run-off occasionally (Table 6.2).

TABLE 6.2

INTENSITY OF RAINFALL AND RUN-OFF AT CERTAIN PLACES IN INDIA

(Average of 5-7 years)*

Particulars		Manjri (5 years) (Maharashtra) (1929-33)	Sholapur (7 years) (Maharashtra) (1934-41)	Bijapur (5-years) (Mysore) (1936-41)
Av. annual rainfall in (inches)		24.67	24.35	18.80
Total No. of rainfalls		212.00	301.00	158.00
No. of rainfalls causing runoff		66.00	75.00	54.00
Percentage slope of runoff plots		3 00	1.18	1.25
Rainfall classes according to quantity per day and percentage of number of rainfalls causing runoff	over 2″	100.00	100.00	100.00
	1″—2″	88.00	83.30	86.30
	½″—1″	66.00	38.90	41.60
	Below—½″	5.80	8.40	16.60

*Kanitkar, N.V. et. al., *Dry Farming in India*. Indian Council of Agricultural Research, New Delhi, 1960.

Slope accelerates erosion as it increases the velocity of the flowing water. Small differences in slope make big differences in damage. According to the laws of hydraulics, a four-time increase in the degree of slope doubles the velocity of flowing water. This doubled velocity can increase the erosive

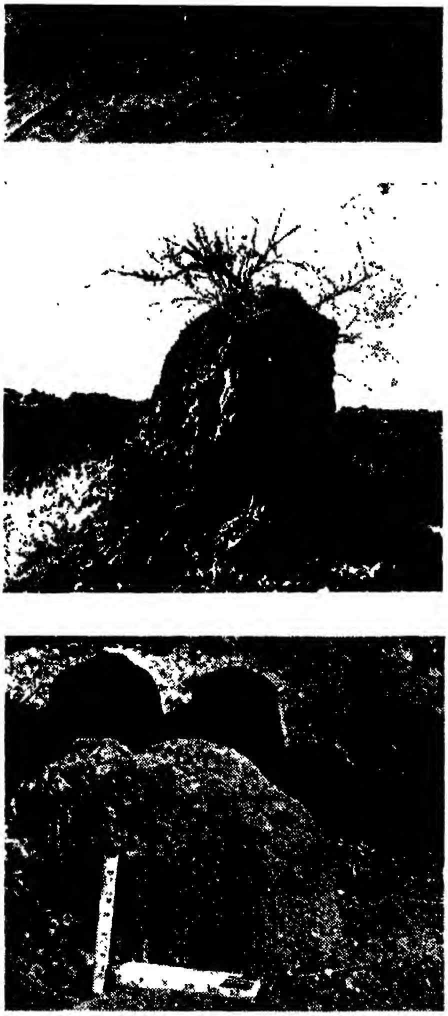

Fig. 6.1 The raindrop may fall with a velocity of 30 feet per second. When the raindrop hits bare soil it beats the soil into flowing mud which flows downhill leaving in place only mounds of earth that are protected by such objects as rocks, mulch, or living vegetation.

Top : A small rock has protected the soil under the rock against splash erosion in Central India

Centre : Shrubs and grasses have protected this mound in an abandoned field against splash erosion, resulting in a residual mound of earth about 10 feet high. (North Central India).

Bottom : Rounded caps of standstone have protected the sandy loam soil beneath them from splash erosion in the 50-inch rainfall belt in Central India.

power four times and the carrying capacity by thirty two times.

Erodibility of soil is influenced by the nature of the soil, particulary its texture, structure, organic matter, the nature of the clay, and the amounts and kinds of salts present. Fine textured and alkaline soils are more erodible. In Indonesia*, *margalite* soils are reported to be highly susceptible to erosion. Studies on the erodibility of tropical soils are meagre. In general, soils with a low silica/sesquioxide ratio are reported to be less erodible. Such soils are quite common in humid tropics, e. g., latosols and other lateritic soils.

The presence of vegetational ground cover acts as an erosion-retarding factor. Forests and grasses are more effective in providing cover than cultivated crops. Vegetation intercepts the erosive beating action of falling raindrops ; retards the amount and velocity of surface run-off ; permits more water flow into the soil ; creates more storage capacity in the soil through evapo - transpiration losses ; checks the abrasive power of wind velocity ; and regulates the hydrological cycle. It is the lack of vegetation that creates erosion-permitting conditions (See Figure 6.2.)

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* Dames, T. W. G., *The Soils of East Central Java.* Contributions of the General Agricultural Research Sta. No. 141: 1-155, 1955. Bogor (Indonesia).

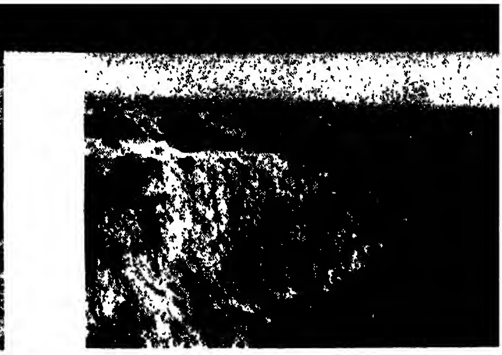

Fig. 6.2 Trees and grasses are effective in protecting the soil against erosion. But when grasses are overgrazed and trees lopped to feed livestock (**Left**), sheet erosion soon sets in. With continued overuse of trees and grasses, erosion becomes more severe and gullies are formed, making the land almost worthless (**Right**).

4. TYPES OF EROSION

Many types of erosion are recognized, depending on the predominant eroding agency and the way it is caused.

Splash Erosion : The falling raindrop at an approximate speed of 30 feet per second is capable of creating a force of almost 14 times its own weight. With this falling force, the raindrops beat up the bare soil surface into flowing mud which splashes as much as two feet high and five feet away. Fine sand and silty textures become dislodged readily. Splash erosion is the forerunner of other types of water erosion. (See Figure 6.3.)

Sheet Erosion : It is the removal of thin uniform layers from the surface of the soil from the entire area, every time a rain of eroding intensity falls. Sheet erosion is caused by : (1) surface creep, (2) vaultation, and (3) suspension. *Surface creep* means movement of soil downhill by a rolling or dragging action of water. *Vaultation* results when turbulent waters cause soil particles to hop or skip as they move downward. Soil particles which never touch the soil surface as they are moved along are carried by *suspension.* Sheet erosion is extensive wherever the soil is unprotected and is very damaging. It continuously keeps on making the soil shallower, with resultant decreasing crop yields. (See Figure 6.4.)

Fig. 6.3 Splash erosion is caused by the falling raindrop (**Left**) striking bare soil and (**Right**) beating it into flowing mud.

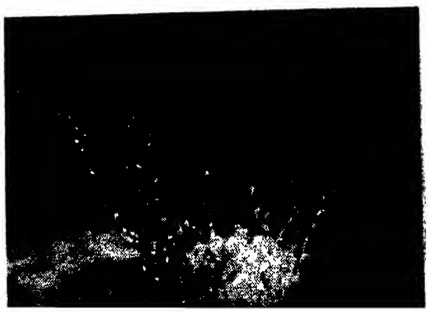

TABLE 6.3
LOSS OF SOIL DURING THE PERIOD 1905—1960 IN SOME FIELDS IN YEOTMAL TALUK OF MAHARASHTRA STATE (INDIA)*

Site No.	Av. depth in inches 1905	Depth in inches 1960	Soil losses from 1905—1960 (55 years). Reduction in depth in inches	Per cent	Loss of depth in inches per year	Loss of soil** in tons per acre per year
1	7.9	3.0	4.9	62.0	0.09	13.4
2	31.5	16.0	15.5	49.2	0.28	42.3
3	8.6	4.0	4.6	53.5	0.08	12.6
4	12.5	6.0	6.5	52.0	0.12	17.7
5	17.3	8.0	9.3	53.8	0.17	25.4
Average	15.56	7.40	8.16	52.44	0.148	22.28

*Personal observations and estimations by one of the authors. (Y.P. Bali).
**Loss of soil in tons per acre calculated on the basis that one acre-inch of soil on the average weighs about 150 tons. Depths of soil were measured from the surface to the top of the C horizon.

Fig. 6.4 This unprotected and improperly managed land is susceptible to severe sheet erosion, leading to rills and then gully erosion.

From Table 6.3 it may be seen that during the 55-year period, the average of the soils at the five sites lost 52.44 per cent of their top soil.

Rill Erosion : The silt-laden run-off starts flowing along the slopes through small finger-like channels. This is rill erosion and is an intermediary stage between sheet erosion and gully erosion. (See Figure 6.5.)

Gully Erosion: As the volume of concentrated runoff increases and attains more velocity on slopes, it enlarges the rills into gullies. Gullies can originate from slight depressions, cart tracks, and cattle trails. Unlike sheet erosion, gully erosion is more spectacular and indicates neglect of land over a long period of time. With the formation of gullies, the land is almost crippled. At an advanced stage, gullies results in *ravines* which are sometime 50 to 100 feet deep and with steep, nearly vertical sides. Ravines present an awful sight of desolation. In India ravines cover about 6 million acres.

Fig. 6.5 A close-up view of incipient rill erosion in a wheat field (**above**), and (**below**) well-developed rill erosion in a cotton field Both photos were taken on blackland clay soil in Maharashtra State, India.

Slip Erosion : It is recognised in the form of landslides and is the result of instability created in large masses of soil due to saturation and moisture pressure. Helped by gravitational pull, big masses of soil and rock bodily slip down, damaging a hillside or an entire field. Slips may also be caused by under-scouring, leverage action of large trees, and seismic disturbances. Their effects are, however, fairly localized.

Stream-bank Erosion : Rivers and streams meander and change their courses by cutting one bank and depositing sand and silt loads on the other. During flash floods, the damage is very much accelerated. Torrents, the

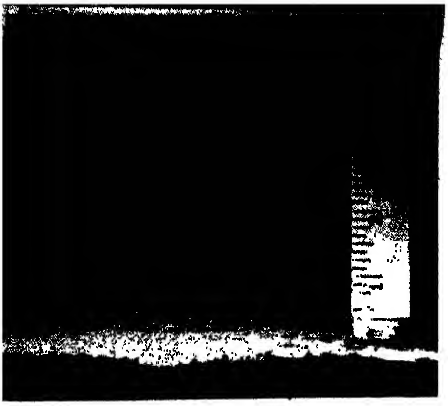

Fig. 6.6 Wind erosion is caused by strong winds acting on dry, sandy soil. Soil particles are moved by saltation, suspension, and surface creep. **Left**: Movement of sand particles during a sand storm.
Right: Sand dunes in Rajasthan State, India, being stabilized by trees and shrubs, (Courtesies: *Left: Agricultural Research Magazine U.S.A Right: Directorate of Public Relations, Rajasthan.*)

rushing streams of rainy seasons, move large masses of soil and boulders and deposit them downstream. Such torrents are called *Chos* in the Punjab State (India), and have affected about 150 thousand acres. The Kosi river in Bihar State (India) is reported to have changed its course westward by 65 miles within the last 100 years.

Wind Erosion: It is caused by strong winds mainly in arid and semi-arid areas, through processes like saltation, suspension, and surface creep which are directly related to the wind velocity. Soil particles are picked up from one location and are blown to another, often hundreds of miles away. Wind erosion causes dust storms; forms sand dunes; buries localities with deposition; and creates drier conditions. Wind erosion is common in India and Pakistan, forming the western part of Tropical Asia. (See Figure 6.6.) It is not common in other Tropical Asian countries except on sandy shores along sea coasts and lakes.

Sea Shore Erosion: This is caused by the striking action of strong waves which combine eroding effects of both wind and water.

5. CAUSES OF EROSION

The supreme cause of excessive erosion is removal of vegetational cover from the soil. Most degradation of forest vegetation is caused by indiscriminate felling and subsequent burning by uncontrolled fires. Grasslands have been overgrazed and made bare. In Cambodia, the nationwide practice of burning forests and grasslands has caused severe impoverishment of the land.

Cultivation has been extended beyond prohibitively steep slopes. Permanent agriculture is possible on certain sloping lands, but not without the adoption of approved soil conservation practices. Up-and-down-the run-off and erosion. At many places the land is not being used according to

Fig. 6.7 Rice cultivation on bench terraces is a common practice in many hilly areas in Tropical Asia In the foreground, stream bank cutting in causing damage to the terraces made in the indigenous way. Such steeply sloping areas are best suited for forests, but as long as people are hungry, they will continue to farm in this manner. Slope cultivation, instead of along the contour cultivation, has accelerated.

its capability. Watersheds are not treated according to their characteristics and requirements. Soil erosion is the most spectacular result of bad land management. In fact, soil can be greatly altered for better or worse by human activities. (See Figure 6.7.)

Shifting Cultivation : It is the most extravagant way of using rich forest soils. The forests are felled and burned, and cleared areas are cultivated for 2-3 years and then abandoned for 5-15 years, and again cleared for cultivation. The practice is more common with tribal communities. It is widespread in most of the Tropical Asian countries. In India alone,

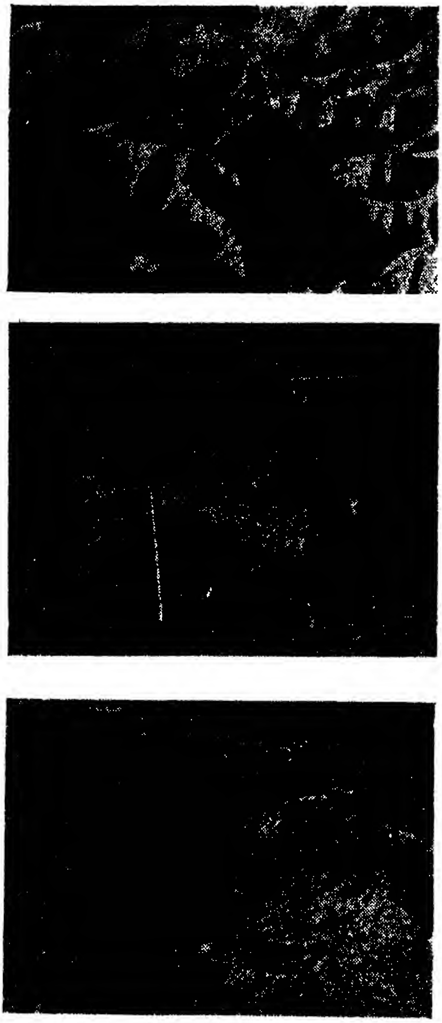

Fig. 6.8 Top : This waste land was once good crop land but too intensive a use combined with no approved soil conservation practices, have resulted in worthless gullies. The land is even worse than useless—it is a public menace—because the soil that has been eroded from here has gone into a hydroelectrical reservoir and decreased the useful life of the reservoir.
Centre : Another type of gully erosion occurs frequently in blacklands, known as tunneling. Note two holes in the surface connected to a tunnel in the centre foreground
Bottom : The same location as on the centre but one year later. Note how the complete soil surface above the tunnel has collapsed and a very active gully is in evidence.

nearly 9 million acres have thus been affected. In different countries, the practice is locally named as *Chena* in Ceylon, *Kainginfing* in Philippines, *Ray* in Cambodia, *Taungya* in Burma, *Ladang* in Malaya, and *Jhumming* and *Podu* in India. The tropical climate is naturally favourable for luxuriant vegetative growth and abandoned areas may get second growth rapidly, yet most of the fertile soil is lost during the period the lands are cultivated, as no approved conservation practices are adopted.

6. EFFECTS OF EROSION

By erosion the soil is lost and its fertility depleted (See Figure 6.8). It is reported that the annual loss of fertility by erosion is 20 times faster than what is removed by the crops. In general, the soil removed by erosion, both by water and wind, is richer in nutrients than the original soil. The soils become shallower, yields are lowered and a food deficit is created. A deficit of forest and grassland products also results. A recent survey over an area of about 4 million acres in the East-Central Java (Indonesia) has revealed that nearly 36 per cent of the area is severely eroded.*

*Dames, T.W.G. *The Soils of East-Central Java.* Contribution of the General Agricultural Research Station, No. 141: 1-155, Bogor, Indonesia 1955.

Fig. 6.9 A well-managed tea plantation provides adequate cover for the sloping land as a defence against soil erosion.

As the water continues to carry away the topsoil, the productivity of the land declines. The sorghum yields under the dry farming conditions of Sholapur (Maharashtra, India)* show that they average 110 pounds per acre in deep soils ; 80 pounds in medium deep soils ; and only 33 pounds per acre in soils from which most of the topsoil has eroded.

Most of the water runs off unutilized to the sea. Flood havocs become more frequent, damaging both life and property. On a moderate estimate, India loses about 500 million rupees (approx. 100 million dollars) annually through flood damages. The fertile lands are damaged by deposition. Dams and reservoirs become silted much before their estimated useful life. Communications are often disrupted. Springs become dry. There is irregular flow of water in streams and rivers. Ground water supplies diminish. Even the climate is affected and drier conditions set in. Ultimately the economy and strength of the nation are sapped.

One favourable situation in the tropical and subtropical countries is the rice culture which involves practices that are in themselves anti-erosion ; for example, the bunded and terraced rice fields in Tropical Asian countries. Similarly there are large areas under plantations of tea, coffee, palm oil, cocoa, rubber, and banana, which also provide sufficient cover against erosion. Large areas in the tropics and subtropics are heavily forested, but their proper management is necessary so that erosion does not set in. (See Figure 6.9.)

*Kanitkar N.V. et al, *Dry Farming in India.* Indian Council of Agricultural Research, 2nd Enlarged Edition, 1960 New Delhi.

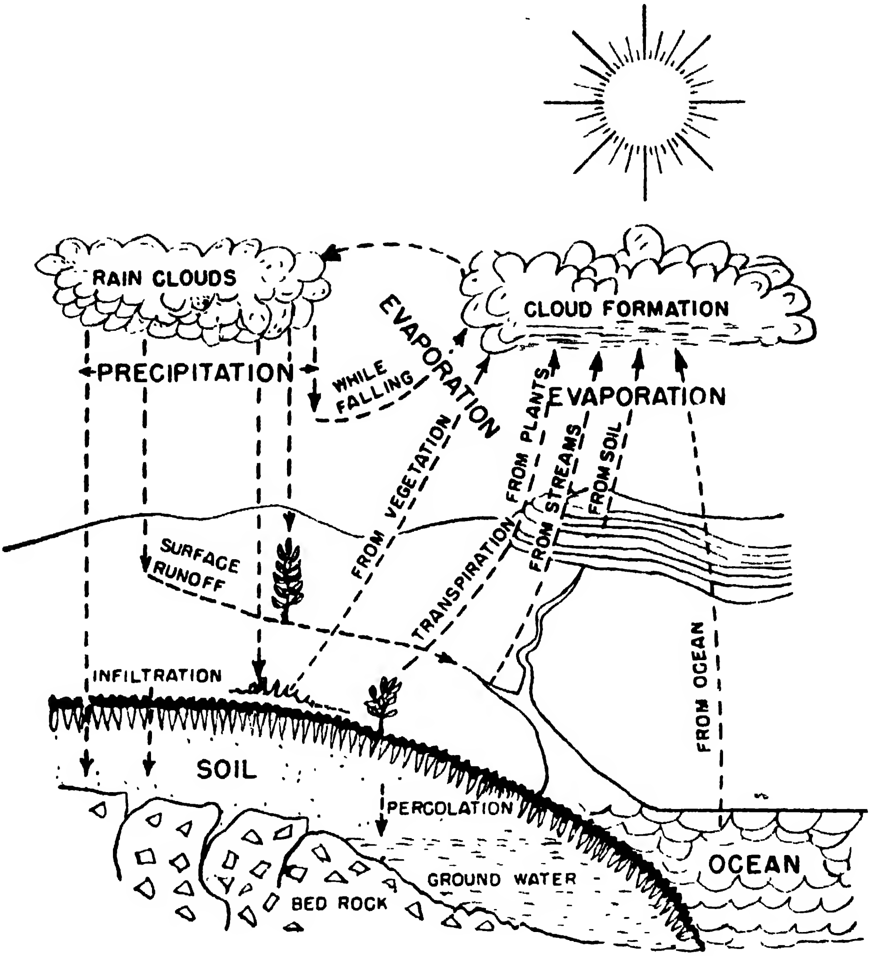

Fig. 6.10 The hydrologic cycle illustrates the movement of water from ocean to clouds to earth to ocean, and from liquid to vapour to liquid, in response to definite physical and chemical laws.

7. WATER CONSERVATION

The main source of water is precipitation, but it is not equally and sufficiently distributed everywhere. In Tropical Asia, although total annual precipitation is quite high, yet the monsoonic climate with alternating dry and wet seasons makes it all the more ill-distributed. Hence, proper conservation of water assumes quite an importance under such tropical conditions. To understand water conservation, it is necessary to study the hydrologic cycle.

8. HYDROLOGIC CYCLE

Water moves in a continuous cycle from ocean to clouds to earth to ocean, and from liquid to vapour to liquid—always in response to physical and chemical laws of nature. These movements of water are known as the hydrologic cycle (See Figure 6.10.)

Moist air from the ocean moves over land and is deflected upwards. As the moist air mass rises, it cools and its ability to hold water vapour decreases. Vapour then condenses into rain drops which fall to earth. Some of the rain is intercepted by the leaves of plants, some runs off into streams, and some enters the soil. Of the water that enters the soil, some is used immediately by plants, some is stored in the soil for later use by plants, and the remainder moves downwards to replenish the water-table. The water-table becomes the source of water for springs and wells.

Of the rainfall that reaches the ground, the amount that enters the soil and is held there in an available form is important from the point of view of plant growth. Sandy soils are capable of holding about one half-inch of available water per foot of soil depth. Clay soils often hold 2 inches per foot. In between these extremes are the loams and silt loams which are capable of holding from about 1-2 inches of available water per foot of soil depth. Man is still not able to control the rainfall very much, but its infiltration and run-off can be regulated to a large extent by improved management practices. Efforts must be made to store and carry over rainwater when it is in plenty to periods when rainwater is not so abundant. (Table 6.4.)

TABLE 6.4

DISTRIBUTION OF SOIL MOISTURE UNDER LOCAL AND IMPROVED CULTIVATION METHODS (INDIA)*

(Average for Cropping Season)

Place	Depth of soil in inches	Local methods of cultivation	Improved methods of cultivation	Difference in favour of improved methods of cultivation
	(Per cent moisture on oven-dry basis)			
Manjri	0—6	18.26	20.48	+2.22
(Maharashtra)	6—12	23.67	26.82	+3.15
April, 1927—Feb., 1928	12—18	23.35	24.98	+1.63
Raichur	0—6	22.28	22.94	+0.66
(Mysore)	6—12	22.15	23.91	+1.76
Oct., 1939—Feb., 1940	12—18	20.82	21.76	+0.94
	18—24	20.76	21.08	+0.32
Rohtak	0—12	7.17	10.82	+3.65
(Punjab)	12—24	8.43	12.42	+3.99
(1937—38)	24—36	10.27	13.07	+2.80

**Source* :—Kanitkar, N. V. et. al., *Dry Farming in India*. Indian Council of Agricultural Research, New Delhi. 2nd Edition, 1960.

9. PRECIPITATION AND LOSS OF WATER

With an average annual rainfall of about 42 inches and a total land surface of 806 million acres, the precipitation source of water in India roughly amounts to about 2,830 million acre-feet. The runoff estimated from most of the river systems is about 1,356 million acre-feet. Of this, India plans to utilize about 11 per cent by 1965.* It is thus clear that there is still a considerable potential of usable water that can be harnessed for the economic uplift of the nation.

Water is lost from the soil in four ways :

1. Surface runoff.
2. Movement downward of drainage waters.
3. Evaporation from soil surfaces.
4. Transpiration through the leaves of plants.

Out of these sources by which the water is lost, run-off is usually the largest and most damaging as it causes erosion.

Probably the variations in precipitation from the normal averages and the season and time when precipitation occurs, determine to a large extent the importance of soil moisture conservation. The main factors in conserving moisture relate to increasing infiltration and storage capacity of soil and reducing run-off and evaporation.

Untamed water is the main cause of soil erosion. Almost all the methods that deal with soil conservation are in principle the methods to control and conserve the water. Therefore, soil and water conservation methods are dealt with together.

Research work on run-off and soil losses and suitable methods to control these losses in Tropical Asian countries is still in its infancy. The results of research evolved in temperate climates cannot be applied directly without testing and modifying them under tropical conditions. However, certain general principles of soil and water conservation are given here.

10. SOIL AND WATER CONSERVATION METHODS

The loss of soil and water under natural vegetation is minimum. But lands must be cleared of vegetation and cultivated to produce basic requirements of the ever-growing human and animal population and the expanding industries. By adopting proper soil and water conservation methods, soil resources can be used advantageously in a perpetual way.

Almost all soil and water conservation measures basically aim at reducing soil and water losses and maintaining and building up the overall

* *Third Five-Year Plan*, Govt. of India Planning Commission, New Delhi, 1961.

productivity of the soil. The most important requirement is to keep the land under cover for as long a time as possible. The cardinal principles of soil and water conservation are to encourage more water to enter into the soil and to reduce the amount and velocity of run-off to a minimum.)

For preventing further damage to the soil, it is essential that indiscriminate felling of forest trees, overgrazing, and cultivation beyond safe limits on sloping land, must stop. To control these menacing practices it may be necessary to enact legislation and to provide public incentives.

Practices commonly used in soil and water conservation are strip cropping, crop rotations, mulching, the planting of grasses and trees, contour tillage, contour bunding, terracing, the use of surplussing arrangements, the construction of ponds and reservoirs, the control of gullies, and streambank control.

Strip Cropping : This practice consists of growing erosion-permitting row crops like cotton and sorghum, in alternate strips with erosion-checking close-growing crops like groundnut, other legumes, and grasses. The run-off water and soil erosion that occur in soil-exposing strips are to a great extent checked and held in the next soil-protecting strip. Experiments at Sholapur (Maharashtra, India) have indicated that strips, 12 or 24 feet wide, of anti-erosion crops like *Makti**, groundnut with normal to 5 times normal seed rate, alternated with 72-feet wide strips of erosion-permitting crops like sorghum, reduced soil losses by 7 to 79 per cent. **Makti* is kidney bean, *Phaseolus aconitifolius*.

Fig. 6.11 Contour strip cropping with cultivation on the contours is very effective soil and moisture losses on gently rolling lands with fairly uniform slopes The crops are groundnut (left) and *Jowar* (right and foreground). (Maharashtra State, India).

The best erosion-checking strip was one 24 feet wide of *Makti* with 5 times normal seed rate. Strip cropping is especially suited on gently rolling lands with fairly uniform slopes. Some experiments with winter sorghum in Maharashtra* (India) have shown about 40 to 100 per cent higher yields in strip cropped areas.

Field strip cropping, contour strip cropping, wind strip cropping, and buffer strip cropping are some of the types of strip cropping. (See Figure 6.11.)

Rotations : Rotation means growing a set of crops in a regular succession over the same field within a defined period of time. Continuous growing of clean-cultivated crops causes more erosion. A good rotation should include an open row crop, densely planted small grains, a spreading legume or legume-grass mixture, and a deep-rooted crop. Rotations help removal of nutrients in a uniform way from greater depths, keep the field covered for a longer period of time, and reduce erosion.

Mulching : Mulches of different kinds minimise evaporation, and increase absorption of moisture. Stubble mulches check erosion as well as supply some organic matter. Results in the 20-inch rain belt in Texas (U.S.A.)** show that after a 2.8 inch summer rain, the moisture penetrated up to 30 inches where 16 tons of mulch per acre was applied as against only 15 inches where no mulch was applied. Table 6.5 shows that a *bajra*† stalk mulch was much more effective in conserving water than a soil mulch.

TABLE 6.5

EFFECTS OF MULCH ON THE CONSERVATION OF SOIL MOISTURE AT ROHTAK (PUNJAB, INDIA)*

Depth in inches	Control (no mulch)	*Bajra* Stalk Mulch		Soil Mulch		
		2 inches thick	4 inches thick	2 inches thick	4 inches thick	6 inches thick
		Per cent moisture on oven-dry basis				
0—3	2.97	14.00	13.64	7.59	7.84	7.17
3—6	8.09	13.23	14.73	9.83	10.18	9.66
6—12	9.98	14.54	14.79	10.13	12.96	13.93

* *Source :* Kanitkar. N .V. et. al., *Dry Farming in India.* Indian Council of Agricultural Research, New Delhi. 2nd Edition, 1960.

*Kanitkar, N.V. et. al., *Dry Farming in India.* Indian Council of Agricultural Research, New Delhi, 2nd Edition, 1960.

**Burnet, E. and C.E. Fisher, Agronomy Abstracts, p. 46. 1955.

†*Bajra* is pearl millet, *Pennisetum typhoideum.*

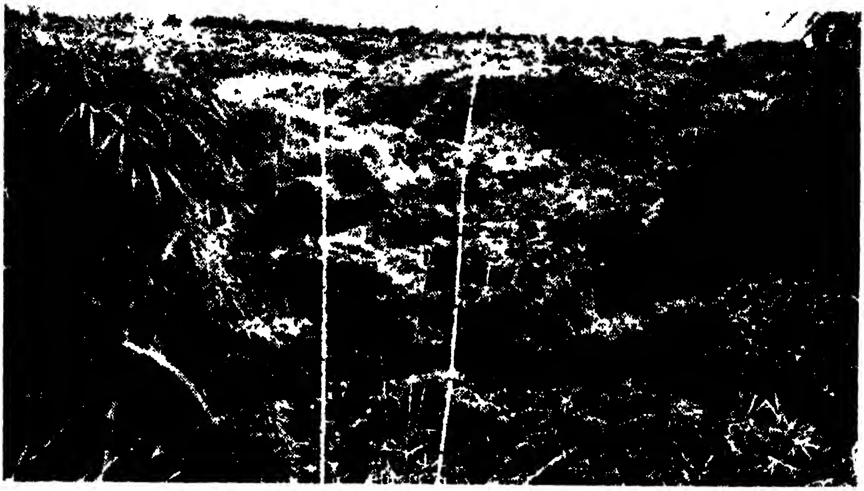

Fig. 6.12 Stabilization of badly eroded areas under grasses (here mostly bamboo) is a good soil and water conservation practice.

Grasses : Their canopy and profuse root system tightly bind the soil against erosion, increase water infiltration, and improve physical characteristics (structure) of soils. Grasses can be grown on lands which are otherwise not suitable for cultivation of crops. They are also used in protecting bunds, waterways, highway alignments, badly eroded areas, gully control, and for stabilising sand dunes. Controlled seasonal grazing in accordance with the carrying capacity of the grasslands is necessary in proper grassland management. (See Figure 6.12.)

Forests : Forests are one of the most important and effective means of conserving soil and water. They are the regulators of water flow in springs, streams, and rivers. Forests must be used in scientifically planned ways, especially in areas which are denuded and are suitable for afforestation. Farm forestry is another important aspect in soil and water conservation. Planting of trees as wind breaks and in shelter belts is necessary to check wind erosion.

Mechanical Practices : These constitute various engineering techniques and structures which further supplement the biological measures. These practices reduce run-off velocity, impound water for a longer time and provide more absorption opportunity, and allow excess run-off water to flow at non-erosive velocity. Depending upon climate, soil type, lay of the land, and hydrological characteristics of the area, the design and details of mechanical practices differ for different regions. When properly built

Fig. 6.13 For reforestation or afforestation of denuded areas, contour trenching on sloping lands is very helpful in catching sufficient rainfall to assure greater success of planted trees or shrubs.

and maintained, these mechanical structures improve the land over a long period of time.

Contour Tillage : Ploughing, harrowing, sowing, and interculturing operations when done on contours are called contour tillage (Fig. 6.11). In contour farming, each furrow which lies approximately on the level, intercepts flowing water, and holds it and allows it to soak into the soil. On gently sloping land and in low rainfall areas, contour cultivation alone is fairly effective for soil and water conservation. It is also used in combination with other measures such as terracing, bunding, and strip cropping. Contour cultivation experiments in dry regions at Bellary (Mysore State, India) have given 10-15 per cent extra yields. Contour cultivation further helps to save power in tillage operations. Contour trenching in continuous or staggered fashion on steeper slopes, and contour furrowing on comparatively gentler slopes, are suitable practices in forest and grassland management. (See Figure 6.13.)

Contour Bunding : The slope of the land is broken up into smaller, more level compartments by constructing earthen embankments of suitable size on contours. Each bund thus holds the rainwater within each compartment. The size, cross-section, and inter-bund spacing, depend on the nature of rainfall, soil, and slope of the area. In low rainfall areas, level bunds are preferable to help increase moisture absorption. In high rainfall areas, the bunds are slightly graded longitudinally to permit the safe disposal of excess water.

In India contour bunding is a major aspect of soil and water conservation programmes. They are quite effective on lands up to 10 per cent slopes.

In India it has been shown that contour bunding alone increases yields by 20-30 per cent. (See Figure 6.14.)

Terracing : The principles and purposes behind terracing are the same as for contour bunding. But terraces are built as broad based alternating channels and ridges laid across the slope, and these ridges and terraces can also be cultivated and crops planted on top of them. Level, retention-type terraces are built in low rainfall areas to conserve more moisture, and slightly graded ones are built in high rainfall areas for safe disposal of excess water. Terracing is a common practice especially in the U.S.A. Terraces are usually recommended only on intensively used, sloping crop land.

Bench Terracing : It is suitable on slopes with gradients usually steeper than 15 per cent. They are laid on contour in the form of a series of steplike platforms. These terraces may be like a table top, sloping outwards, or sloping inwards, with or without grades depending upon rainfall, soil, and other characteristics of the area. Bench terraces of many patterns are in vogue in many Tropical Asian countries. These terraces always need proper drainage ways and maintenance. It has been found that in India on black cotton soils and in Indonesia on margalite soils, it is difficult to

Fig. 6.14 The various State Departments of Agriculture in India usually supervise the construction of bunds. **Top :** A general view of a field that has been completely bunded, with suitable weirs provided for excess runoff water. **Centre :** Construction of a bund by villagers that had been surveyed and staked out by the staff of the Department of Agriculture. **Bottom :** A close-up of a properly constructed loose rock waste weir for surplus impounded water to flow out without causing erosion.

Fig. 6.15 Bench terraces are fairly common in hilly lands in Tropical Asia.
Left : General view of a Soil Conservation Research Station in Madras State, India, showing an entire hill that has been bench terraced.
Right : Close-up of inward sloping bench terraces on recently cleared land in Madras State, India.

maintain bunds and terraces because of the excessive cracking of the soil upon drying. (See Figures 6.7 and 6.15.)

(**Surplussing Arrangements :** For safe removal of excess run-off water, it is essential to provide suitable outlet structures at proper places so that no harmful effects of water-logging, eroding, gullying, or damage to other conservation structures are caused. Some of the important surplussing arrangements are waste weirs, grass waterways, and diversion ditches. (See Figure 6.16.))

Practices such as *basin listing* (scooping out small basins at regular intervals on contours), *pitting*, *pan breaking*, and *sub-soiling*, also permit more water to go down into the soil and to increase the water storage capacity of the soil, thus decreasing runoff and erosion.)

(**Ponds and Reservoirs :** At suitable places with possibilities of storing water, ponds and tanks with earthen or masonry embankments are recommended water conservation practices. They are also very useful to some extent as a flood control measure. In many parts of India, village

Fig. 6.16 A grass waterway is being constructed for the safe removal of excess runoff water. Note that the grass sod has been planted in parallel strips about 10 feet apart.

ponds are very common. Reservoirs constructed for medium and major irrigation purposes also help in water conservation

Gully Control : To control and stabilise gullies requires diversion bunds and channels to control the extension of gullies; the sloping of gully sides for establishing vegetation ; and suitable temporary and permanent structures such as check dams, overflow dams, flumes, and drop inlets. Invariably, the gullies should be established under permanent grass and tree vegetation. Sometimes a gully may be adequately stabilised by converting it into a paddy field. (See Figures 6.17 and 6.18.)

Streambanks and Torrents Control : Vulnerable stream-bank turns should be protected by providing spurs, jetties, rivetments, and retaining walls. For torrent correction, works such as barrages, paved channels, levees and spurs, have to be undertaken. Finally, such areas need to be stabilised under permanent vegetation.

Although most of the conservation practices are individually effective to some extent, yet for an efficient and most effective soil conservation programme, suitable combinations of various practices as per the requirements of the problem, and the need and capability of a particular area, are essential. Some practices, in

Fig. 6.17 Above : A gully has been controlled by a dam of loose rock, and in addition, the pond will supply water for livestock.

Below : A concrete dam has been constructed across the *nalla* to help in controlling floods and to provide water for people and livestock in several villages in East Central India.

Fig. 6.18 A permanent loose rock dam has been constructed to control a large gully in India.

fact, are supplementary to one another. The most effective practices are those which would permit less than 3 tons per acre of annual soil loss.

11. DRY FARMING IN INDIA

Over large areas, estimated to cover about 140 million cultivated acres, the rainfall is low and erratic in its distribution. Proper moisture conservation and its timely utilization are the main problems. Soil erosion is equally problematic where lands are sloping.

Improved dry farming practices, evolved as a result of research work in India, deal with bunding, both contour and compartmental, to conserve more rain water and reduce erosion ; proper ploughing, harrowing, interculturing, and fallowing, to increase moisture absorption and reduce evaporation losses; suitable crop varieties, rotations, reduced seed rates and wider spacing for maximum utilization of available moisture; and the use of fertilisers and manures for higher yields. The details of these practices vary in different regions as per requirements of local conditions.

Contour bunding alone has enhanced yields of crops by 25-30 per cent in India. In some of the farmers' field trials wherein low seed rate, manuring, and more interculturing were superimposed over bunded areas in Raichur, Osmanabad, and Aurangabad districts (India),* the yields of winter sorghum and summer cotton increased by 47 to 121 per cent, At Rehmankheda** farm in Uttar Pradesh (India), the badly eroded lands which were abandoned for crop production, when brought under conservation treatment, have shown continuous increases in yields by about 900 per cent within the last 10 years.

12. WATERSHED APPROACH

Watershed approach is important because unless the upper catchment is protected, the conservation measures on the lower catchment are often liable to damage from uncontrolled run-off from upper areas. As a matter of fact, the stability of land-use in the lower valleys is dependent on the way the upper hilly catchments are used. Further, the watershed approach leads to reduction of flood hazards—a broader aspect of conservation. For a sound soil and water conservation programme, the watersheds should be

* Kanitkar, N.V., et al., *Dry Farming in India*. Indian Council of Agricultural Research, New Delhi, 1960.

**Khan, A. D., *It Can Certainly be Done*. Jour. Soil and Water Cons. in India Vol. 8. No. 2 and 3. 1960. pp. 61-71.

surveyed, grouped into capability classes, and treatments planned for each capability class.

Conservation of soil and water, therefore, is not merely an anti-erosion and anti-run-off approach, rather it is a comprehensive and integrated approach of changeover from neglectful and wasteful use of these resources to intelligent, protective, and fruitful use of soil and water. It is, in fact, a preventive, curative and building-up approach by which these resources can be used to produce the most without waste.

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COLLOIDAL PROPERTIES OF SOIL

" No one thrives by tilling sandy soil, and no one is ruined by ploughing clay."

ANCIENT TAMIL PROVERB

Thomas Graham in 1849 found that some substances diffuse in water very rapidly and others very slowly. The rapidly diffusing substances, mostly crystalline in the solid state, were called *crystalloids* by Graham while gum and albumin (amorphous substances) were called *colloids*. The differences in the two classes of substances were so great that Graham spoke of "two worlds of matter". This distinction is not true in general. A crystalline substance like sodium chloride (NaCl) can be obtained in colloidal condition while albumin may be obtained in crystalline form.

The criterion for determining whether a substance forms a colloidal suspension or a true solution is the size of the dispersed particles; and it is therefore more correct to speak of a *colloidal state* of a substance than of a *colloidal* substance. The sizes of particles in true solutions and in colloidal suspensions are as follows :

	Diameter of Particle (in millimicrons)
True solution	0.2 to 1 mμ.
Colloidal suspension	1 to 200 mμ.

Various kinds of colloidal dispersions are possible. A few examples are :

Solid in liquid	...	White of an egg, India ink, clay in water.
Solid in gas	...	Smoke in atmosphere
Liquid in liquid	...	Milk (fat in water)
Liquid in gas	...	Clouds, fog in atmosphere.

Colloidal particles float in a medium and do not tend to settle. Some large colloidal particles may settle very slowly. Colloids are therefore sometimes referred to as dispersed systems. The substance in solution is termed as the dispersed phase while the medium in which the particles are dispersed is called the dispersion medium. The commonest colloids are those containing minute solid or liquid particles suspended in a liquid medium.

Adsorption : The surface exposed by colloidal particles is very large for a given weight. For example, take a cube with 1 cm. edges. The surface area exposed by this cube is equal to 6 square centimeters. When this cube is subdivided into 8 cubes of edges 0.5 cm., the surface area exposed is 12 sq. cm. If this division is made into 10^3 cubes such that each side is equal to 0.1 cm., the surface area is 60 sq. cm.

When this subdivision is carried on until the parts are as small as the colloidal particles, say 10 $m\mu$ we would have 10^{18} cubes with each side of cube being 10 $m\mu$. The surface area exposed would be equal to approximately 16 million sq. cm. or 0.4 acres. Thus, the smaller the size of the particles, the greater the surface area exposed by them. Due to the large area surface exposed by colloidal particles, they have tremendous adsorptive properties.

Electrical charge : Colloidal particles often have an electrical charge, some positive and some negative. Colloidal clay is negatively charged and thus attracts positively charged ions (cations).

Coagulation of colloidal particles : The colloidal particles are coagulated by adding an oppositely charged ion, or in some instances by heating them. For example arsenic sulphide is coagulated by adding sodium chloride (effect is due to Na^+ ions), and clay is coagulated by the use of alum (Al^{+++} ions).

Tyndal Effect : Dust particles floating in air form a colloidal suspension. If a strong beam of light is passed through such a colloidal suspension, the particles become visible, and they appear bigger than they really are. This is due to diffusion of light by colloidal particles. Such an effect is termed, "Tyndal Effect".

Brownian movement : Colloidal particles when seen under an ultramicroscope are found to be in continual motion. This motion is called Brownian movement, after the English Botanist, Robert Brown.

Dialysis : Colloidal particles are retained by a porous membrane, for example, a parchment paper, while crystalloids pass through. Thus

colloidal particles can be purified by enclosing them in a parchment bag and placing it in water. Crystalloids present as impurities pass through, leaving a pure suspension of colloids. This process of separation of colloids from crystalloids is called dialysis.

I. SOIL COLLOIDS

In the scientific study of soils, chemical interest and experimental difficulties increase as the particle size of the material decreases. The larger particles on account of their small surface area are chemically inactive. The seat of chemical activity in soil resides in the colloidal particles. With the exception of pure sands, all soils contain particles of colloidal size. There are two distinct types of colloids in soil ; inorganic or mineral colloids and organic or humus colloids. These two types of colloids exist in very intimate mixture or complex and it is difficult to separate their properties. The inorganic colloids occur almost exclusively as clay of various kinds while the organic colloids are humus (organic matter).

In the study of mechanical analysis of soil, the clay fraction is defined in terms of particle size (or settling velocity). The particles with a diameter less than 2 microns (2 μ) are included in clay. As the upper limit of colloidal clay particles is 0.5 μ, it is at once apparent that clay as separated in mechanical analysis includes colloidal and noncolloidal fractions. While sand and silt are mostly finely ground and unaltered primary minerals mostly quartz, clay is composed predominantly of secondary minerals, formed as products of weathering which are not found in the parent rock. These secondary minerals rarely occur in particles larger than 2 μ. They comprise the particles that impart the dominant physical and chemical characteristics of clay. Certain soils contain material of secondary origin, i.e., products of weathering in fractions other than clay and the latter may also contain a portion of unweathered material. The coarser fractions of clay, particularly particles larger than 0.5 μ in diameter, may contain appreciable amounts of quartz and sometimes of mica, but the finer fractions, particularly below 0.2 μ, are almost entirely clay minerals or other products of weathering such as hydrated oxides of iron, aluminium, titanium, manganese, and silicon. (See Figure 7.1.)

Two groups of clays are recognised, silicate clays and iron-aluminium hydrated oxide clays. The latter generally occur in tropical and subtropical countries while silicate clays are characteristic of temperate regions.

Fig. 7.1 A soil containing large amounts of colloidal clay will swell upon wetting and shrink upon drying.

Above : A clay soil in a field that has formed wide cracks upon drying. **Below :** A similar soil nearby that has dried more and has formed a large number of smaller cracks.

2. CHEMICAL COMPOSITION OF CLAY

The chemical analysis of clay indicates the presence of four main constituents silica, alumina, iron, and combined water. These make up from 90 to 98 per cent of the colloidal clay. The colloidal matter of soil contains a higher proportion of the important plant nutrients such as Mg, Ca, and K, than does the non-colloidal fraction. It is now known that clay is a mixture of hydrated alumino-ferro silicates of varying composition mixed in some cases with an excess of sesquioxides or silica. A typical analysis of the soil and colloidal matter separated from it, is given in Table 7.1.

It will be noted that SiO_2 content of the colloidal fraction is much lower than that of the corresponding soil, while the Fe_2O_3 and Al_2O_3 content is much higher. The plant nutrients also reside chiefly in colloidal matter.

TABLE 7.1

CHEMICAL COMPOSITION OF SOIL AND COLLOIDAL MATTER*

Constituent	Fine sandy loam (Mississippi U. S. A.) per cent	Colloidal matter (from same soil) per cent
SiO_2	93.66	40.35
Al_2O_3	2.57	31.04
Fe_2O_3	0.93	10.11
CaO	0.16	0.51
MgO	0.06	0.72
K_2O	0.45	0.81
Na_2O	0.15	0.24
P_2O_5	0.03	0.42
Organic matter	0.77	4.26
$\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$	50.00	1.83

* *U.S.D.A. Technical Bulletions* No. 170, 229, 502, and 594 ; and Bulletins No. 551 and 1311.

Early workers of soil science have visualized the clay particles as spherical. In fact while discussing texture and mechanical analysis of soil, the size of the particles is mentioned as a diameter. Electron microscopic studies of clay minerals have definitely established that the particles occur in layers or flakes like pages of a book. Each clay particle is made up of a large number of plate-like structural units. The different units or flakes of clay mineral are held together with varying degree of force depending upon the nature of the clay mineral.

Clay particles due to their small size expose a large amount of surface area. Besides, the plate-like structure of clay also contributes towards greater surface area on which moisture and cations are held. The finer the fraction of soil or clay, the greater the percentage of hygroscopic moisture.

Clay colloids are negatively charged (anions) and therefore attract a large number of positively charged ions (cations). The individual crystalline particle is termed "micelle" or "microcell". The clay micelle is lyophilic (water loving) and adsorbs a large quantity of water over its surface. Besides, the cations themselves hold water. This hydrated water layer of cations and clay particles greatly influences the closeness with which the cations may remain with the negatively charged particle. Na is more highly hydrated (surrounded by water) than K, and Mg more than Ca.

The colloidal particles, due to their small size, tend to remain in suspension. The settling velocity under force of gravity is very slow; also, the large surface of the particle causes resistance to settling. The particles are small enough to have a diffusing motion which may be upwards as well as downwards. The rate of diffusion in colloidal particles is slow. A sphere of quartz of diameter 0.2 μ falls through water at the rate of 3.5×10^{-6} cm. per second or one cm. in 80 hours, while a sphere 0.02 μ (20 mμ) may take about 100 times as long a time, i.e., about a year to fall through 1 cm. Meanwhile, diffusion may carry the particle back to the same place.

If several colloidal particles coalesce, an aggregate is formed and sinks to the bottom, due to its large size and higher settling velocity. The solution is said to flocculate. The colloidal particles are negatively charged, and like charges repel each other. The particles are also intensely hydrated, i.e., they have little tendency to coalesce, and thus remain stable. The stability of a colloidal system is determined by (a) the nature of adsorbed cations, (b) total salt concentration, and (c) the nature of the colloidal particles.

If the cations are held close to the particle, the negative charge would be neutralized and the colloidal particles would tend to settle. Na cations are highly hydrated and are monovalent; they are not so closely bound with the negatively charged, immobile particles. Thus, the particles continues to offer resistance to aggregation and do not flocculate. Ca cations are divalent and are more tightly bound with the clay particle and are not as easily displaced as sodium. Thus, calcium ions are able to neutralize the negative charge more efficiently and the colloidal system tends to flocculate. In a similar manner trivalent ions like aluminium (Al^{+++}) are still more efficient in flocculation of colloidal systems or increasing aggregation, than divalent and monovalent cations.

A colloid in which hydrogen ions occupy the positions on the surface is also easily flocculated since H ions are the most tightly bound with the clay particle, and like any weak acid, ionise to a very small degree. The neutralization of charge encourages aggregation or unstability of the colloidal system, and the particles settle. The more alkaline the medium, the more stable the colloidal system. The reason is that clay is a weak acid which ionises less than its alkaline salts. Thus Na-clay produces deflocculation and Ca-clay encourages aggregation.

The effect of salt concentration is expressed on the simple principle that the greater the total salt concentration, the greater the number of cations near the negatively charged clay which tend to neutralize the charge. However, there is competition between the salt and the colloid for the water of hydration which normally sheaths the colloid.

The clay colloids from different soils differ greatly in their properties. This is partly due to the particle size distribution within the clay itself (or within the colloids themselves) and partly due to the nature of the colloidal particles themselves. Two soils having the same clay content may have different properties. The finer the particle size of clay, the greater the intensity of colloidal properties. If the two soils have the same nature of clay minerals the difference in properties is explained by the differences in particle size distribution of clay. However, if the particle size distribution in the soils is similar, the differences in properties are due to differences in nature of clay, i.e., the nature of clay minerals predominant in a particular clay.

If two hydrogen saturated colloids are prepared by decantation from black cotton soil and from red laterite soil, the black soil colloid is much stickier, swells more on wetting, cracks heavily on drying, and forms a more stable colloidal suspension in water than the laterite colloid. The red laterite soils are friable and porous and can be worked soon after rain. These two colloids represent two main groups of colloidal clay materials. The colloids from black soils are relatively high in silicon and low in iron and aluminium; on the other hand, red soil colloids are relatively low in silicon and high in aluminium and iron (or *sesquioxides* as Al_2O_3 and Fe_2O_3 are often called). The mechanical composition and silica-alumina ratios of these two types of clay are given in Table 7.2.

The laterite soils are predominantly a kaolinite-type of clay minerals, while black cotton soils are characterised by a predominance of montmorillonite-type of clay minerals.

TABLE 7.2

MECHANICAL COMPOSITION OF A LATERITE AND A BLACK COTTON SOIL AND SILICA-ALUMINA RATIOS OF THEIR CLAY

Soil type and location	Coarse Sand %	Fine Sand %	Silt %	Clay %	RATIO: $\frac{SiO_2}{Al_2O_3}$ of clay
Laterite Soil (Raipur, Madhya Pradesh, India)	60 8	9.7	11.6	11.2	1.87
Black Cotton Soil (Akola, Maharashtra, India)	10.1	15.9	19.6	44.8	4 30

Source · Mukherjee, J N and R.P. Mitra, *Symposium on the Black and Red Soils of Southern India.* Indian Soc. Soil Sci. Bull. No. 2 (1939) pp 51-53.

3. STRUCTURE OF CLAY MINERALS

If clays are examined under an electron microscope or an x-ray, their crystalline structure can be seen. All clay crystals are composed of one of two types, known as two-layer or three-layer crystals. The two-layer type consists of one layer of silicon and oxygen atoms and the other layer of aluminium and oxygen atoms, all in definite spatial arrangement. Three-layer clay crystals have two outside layers made of silicon and oxygen and the middle layer of aluminium and oxygen.

An example of a two-layer type of clay crystal is kaolinite, a diagrammatic sketch of which may be seen in Figure 7.2. This figure portrays the unit arrangement as one layer of Al_2O_3 and one of SiO_2. Whereas the entire crystal consists of many of such units, only two units are shown here. In addition to its two-layer characteristic, another feature of kaolinite is the non-expanding space between the sheets. The rigid crystal structure is responsible for the low cationic exchange capacity, because there is not

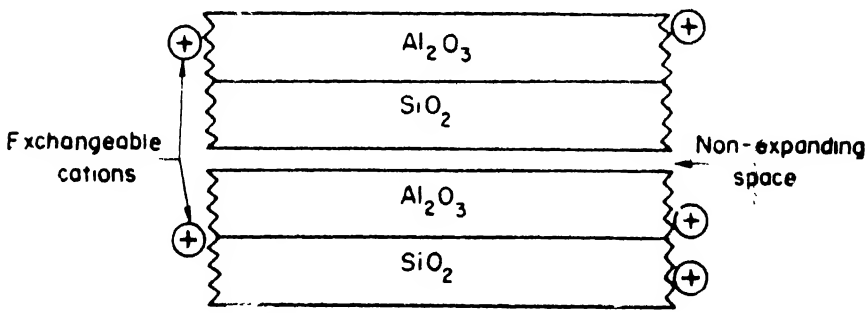

Fig. 7.2 Diagram of a kaolinite clay crystal.

sufficient space between the sheets for this activity. The rigid structure also helps to explain the fact that kaolinite is not very plastic when wet because water cannot get between the sheets. The structural formula of kaolinite is $(OH)_8 \cdot Al_4 \cdot Si_4$ O.

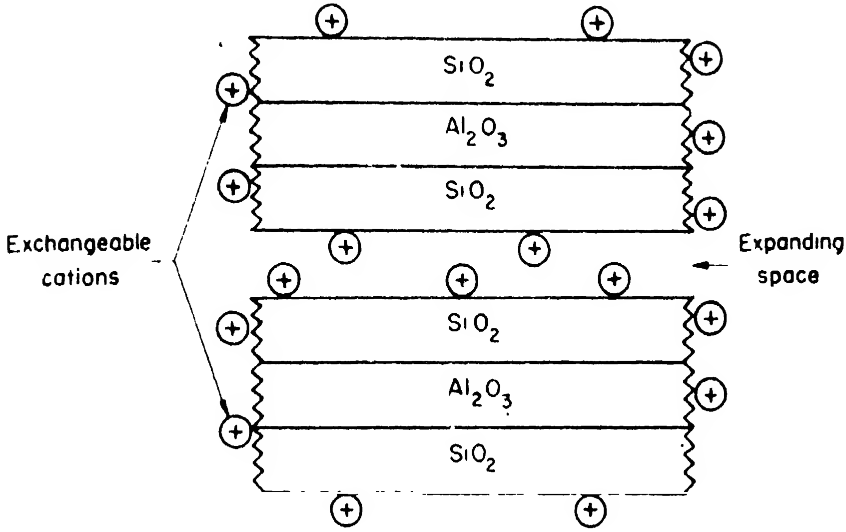

Fig. 7.3 Diagram of a montmorillonite clay crystal.

Montmorillonite is the best-known example of a three-layer type of clay crystal, as seen in Figure 7.3. In this mineral, the unit consists of a layer of SiO_2, one of Al_2O_3, and another of SiO_2. The complete crystal consists of many such layers, but in this diagram only two are shown. There is an expanding lattice which allows for an exchange of cations between each two adjoining sheets. This mineral's cationic exchange capacity is therefore greater per given weight of soil than that of kaolinite. The plasticity of montmorillonite is also higher because water can enter between the sheets. The structural formula is : $(OH)_4$ - Al . Si . O_{20} · xH_2O.

Hydrous micas : Often associated with the montmorillonite clays is another group called hydrous mica of which illite is the most important. Illite has a similar structure as montmorillonite, i.e., 2 : 1 lattice structure, 2 silica sheets enclosing an alumina shee. However about 15 per cent of silicon in silica sheets is substituted by aluminium. The excess of negative charge is satisfied largely by potassium in the interlattice layers, thus making the lattice structure of the nonexpanding type. The properties of water adsorption, cation exchange, ease of dispersion and other physical properties

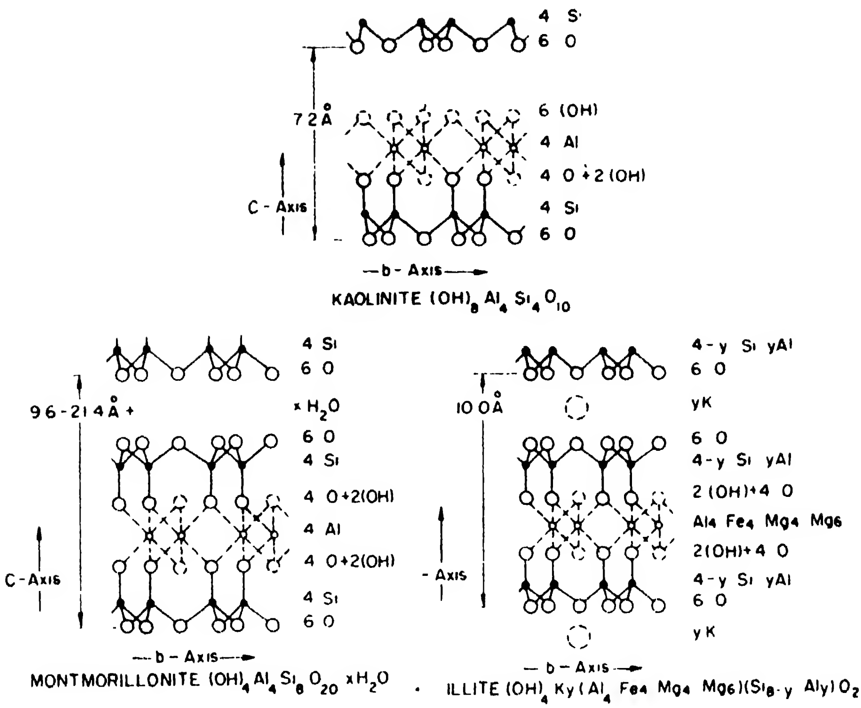

Fig. 7.4 Crystal structure of kaolinite, montmorillonite, and illite.

lie in between those of kaolinite and montmorillonite type of minerals. The structural formula is $(OH)_4K_y$ $(Al_4 \cdot Fe_4 \cdot Mg_4 \cdot Mg_6)$ $(Si_{8-y}\ Al_y)$ O_{20}.

The comparative properties of the three types of clay minerals are given in Table 7.3.

The detailed structural units in each type of clay mineral are shown in Figure 7.4.

Hardon (1950) as quoted by Mohr and Van Baren (1954) have reported the contents of nonexchangeable cations in Indonesian soils which is given in Table 7.4.

Distribution of clay minerals : Clay does not consist of a single mineral. A mixture of different clay minerals is present in clay but one type is usually predominant. Such a mineral composition of clay varies in different horizons of a profile but they are different in different climatic zones. The differences in composition also arise due to differences in parent material from which the soils have been formed. A general distribution of predominant clay minerals as found in different soil-climatic regions is given in Table 7.5.

TABLE 7.3

COMPARATIVE PROPERTIES OF DIFFERENT TYPES OF CLAY MINERALS

Property	Kaolinite	Illite	Montmorillonite
1. Structure	1:1 lattice	2:1 lattice	2:1 lattice
2. Substitution	No substitution	Substitution in silica layer by aluminium	Substitution in alumina sheet by Mg or Fe
3. Nonexchangeable cations	None	K	Mg
4. Base exchange capacity me/100 gm.	3-15	15-40	80-100
5. Anion exchange capacity	High	Medium	Low
6. Physical properties			
(a) Cohesion & plasticity	Practically no cohesion and plasticity	Medium in cohesion & plasticity	Highly plastic and cohesive.
(b) Porosity & permeability	Porous & Permeable	Medium in porosity and permeability	Low in porosity and permeability.
(c) Size	Coarse particle size	Medium in particle size	Fine particle size.

TABLE 7.4

NONEXCHANGEABLE BASES IN THE CLAY FRACTION OF DIFFERENT INDONESIAN SOILS (AFTER HARDON, 1950)*

Soil	Nonexchangeable bases Ca	Mg	K	Na
	Milliequivalents per 100 gm. of soil			
Lateritic soil	10.7	17.3	2.3	30.4
Marl soil	18.7	75.1	5.0	44.6
Limestone soil	9.3	26.7	1.8	33.2
Grey earth	7.1	11.8	5.1	21.4

**Source :* Mohr E.C.J. and F. A. Van Baren, *Tropical Soils*, Interscience Publishers Ltd. London, 1954.

Hydrated oxide clays : These consist of hydrated silica, ferric oxides, and aluminium oxides. These usually occur in coarser fractions of clay or silt. The colloidal properties of aluminium hydroxide are similar to those of ferric hydroxide. The hydroxide clay or hydrated oxides of iron and aluminium occur sparingly in temperate regions but are especially important in tropical and subtropical soils, particularly in laterite soils. The yellow, brown, or red colour of many soils suggest the presence of iron and aluminium hydroxide. Not much is known about hydrous oxide clays. They have been considered to be amorphous.

TABLE 7.5

MINERAL COMPOSITION OF SOME SOILS OF INDIA

Soil type	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Non-exch. MgO	Non-exch. K_2O	C.E.C. me/100 gm.	Dominant clay mineral
Black soil Indore	3.6	3.0	0.88-2.74	1.4-2.75	62	M (80%) I (20%)
Delhi alluvial soil						
0-7″	3.2	2.4	0.82	6.55	33.5	I (80%) (M)
67″-91″	3.7	2.8	1.13	3.28	43.5	I (40%) (M)
Yellow *Matasi* soil (Raipur, M.P.) 0-40″	1.8-2.0	...	0.1 -1.3	...	38	K (M)
Karnal, (Punjab) 0-26″	2.0	...	0.84-1.28	2.3-3.9	23	K (M)

K=Kaolinite M=Montmorillonite I=Illite. Minerals written in bracket are present in small amounts.

Source. Roy, B.B., *Clay Constituents of Some Indian Soils*. Indian Society of Soil Science, Bull. 6, pp 121-123, 1951.
Roy, B.B. and S.C. Das. *Electrochemical Properties of Hydrogen Clays from Several Indian Soils in Relation to their Mineralogical Make-up*. Proc. Symposium on Soil Research N.I.S.I. Indian Science Congress, New Delhi, 1954.

The presence of hydrated oxides confers desirable physical properties such as porosity, permeability, and ease of working and maintenance of desirable tilth.

4. ORGANIC SOIL COLLOIDS

Organic colloids are due chiefly to the presence of humus in soil. Humus is the product of decomposition of plant and animal residues, but it is distinct in structure from the original organic matter. It is an amorphous, brown to black material. In chemical composition, humus contains approximately 30 per cent each of lignin, protein, and polyuronides (complex sugars plus uronic acid). Humus is relatively stable organic matter, yet it is slowly decomposing, dynamic, and ~~less stable~~ than colloidal clay.

Organic colloids may make up an appreciable portion of the colloidal content of soils. In fact in sandy soils it may form the major part of colloids. The properties of organic colloids are affected by the nature of adsorbed ions in much the same manner as the inorganic colloids. Humus colloids are composed of carbon, hydrogen, oxygen, and nitrogen, instead of silicon, aluminium, and oxygen, as in clay colloids. On a weight basis, organic soil colloids have 5-7 times higher adsorptive properties for water

and cations than inorganic colloids. Colloidal humus has an exchange capacity of approximately 400 m.e. per 100 gm. as compared with 60-100 m.e. for colloidal clay. Organic colloids are of particular importance in sandy soils since it is not practicable to improve them by addition of clay. But the addition of organic matter improves for only a few months the retention capacity of soil for moisture and nutrients.

5. CATIONIC EXCHANGE

If a filter paper is placed in a funnel and several grams of soil are added, then a solution of ammonium acetate is leached through the soil, the filtrate will contain calcium, magnesium, potassium, sodium, and hydrogen. Filtrates from most soils will contain at least traces of all of these cations. Where did the cations come from when only the ammonium cation was added ?

The NH^+_4 replaced calcium, magnesium, potassium, sodium, and hydrogen on the surfaces of the clay crystals and humus particles. These cations were released to the soil solution and were moved down into the filtrate. This mechanism is known as cationic exchange.

Cationic exchange takes place when any cation is added to the soil, such as Ca^{++} when lime is used, K^+ from potassium fertilisers, and NH^+_4 from anhydrous ammonia, ammonium phosphate, or ammonium sulphate. The exchange of cations takes place almost entirely on the surfaces of clay crystals and humus particles. This is because these surfaces have a net negative charge and therefore attract positive ions (cations).

The exchange of cations in the soil takes place between :

1. Cations in the soil solution and those on the surfaces of clay crystals and humus.

2. Cations released by plant roots and those on the surfaces of clay crystals and humus.

3. Cations on the surface of either two clay crystals, two humus particles, or a clay crystal and a humus particle.

The cation exchange reaction is so quick as to appear instantaneous. The reaction is also reversible. If the colloid saturated with calcium is treated with sodium chloride, calcium can be displaced. However, if the resulting calcium chloride is not removed from the medium, it would replace sodium from the exchange complex, until an equilibrium is attained whereby the colloid would be charged with both calcium and sodium. If it is desired to replace all calcium from the exchange complex, the soil is leached with sodium chloride so that calcium is constantly being removed

and has no chance to react with the soil colloid to displace sodium. The reaction may be represented as follows :

$$\text{Calcium Clay} + 2\ NaCl \longleftrightarrow \text{Sodium}_2\ \text{Clay} + CaCl_2$$

All cations are not adsorbed with equal tenacity for a clay saturated with a given cation, it has been shown that the replacing power of the alkali metal cations increases with the atomic weight. The potassium ion for example is a more powerful replacer than the sodium ion and is more readily adsorbed by the clay. This same rule holds true for alkaline earth cations. Further, divalent cations are more effective than the monovalent ones. Hydrogen is an exception ; it is the most tenaciously held by colloids, and it is the most powerful replacer of cations. Thus the power of replacement is :

$$H > Ca > Mg > K > Na$$

6. CATION EXCHANGE CAPACITY (C.E.C.)

The cation exchange capacity is easily determined by leaching the colloid or the soil with neutral ammonium acetate. The excess of ammonium acetate is removed by washing with alcohol. The adsorbed ammonia is displaced and distilled with MgO. The ammonia is adsorbed in standard acid (N/10) solution. The excess of acid is titrated with standard alkali (N/10).

The results are expressed in terms of milli-equivalents per 100 gm. of soil or colloid. For example, 1 ml. N/10 H_2SO_4 = 0.0017 gm. NH_3

= 1.7 mgm. NH_3

= 1.7/17=0.1 m.e. NH_3

If 10 gm. soil was used for leaching with normal ammonium acetate, the cation exchange capacity (C.E.C.) can be calculated as follows :

$$\text{C. E. C.} = n \times 0.1 \times 0.1 \times \frac{100}{10} = \text{m.e. per 100 gm. of soil,}$$

where n=ml. N/10 sulphuric acid used for distillation with 10 gm. of soil.

There is a great advantage in expressing the results in milliequivalents because 1 m.e. of Ca is equivalent to 1 m.e. of Na, Mg, K, H, and so on. The cation exchange capacity is thus expressed in a uniform manner. The cation exchange capacity of some representative soil types of India and Pakistan is given in Table 7.6, and from Philippines in Table 7.7.

7. SOIL TEXTURE AND EXCHANGE CAPACITY

In general, the more clay there is in a soil, the higher the cation exchange capacity (C.E.C). Sandy soils have, on the average, 0 to 5 m.e. of cation

TABLE 7.6
CATION EXCHANGE CAPACITY (C.E.C.) OF SOME INDIAN AND PAKISTAN SOILS

Soil and location	Cation Exchange Capacity (C.E.C.) (m.e. per 100 gm. soil)	pH	Clay %
1. Red Laterite Soil from Government Agriculture Farm, Dacca (East Pakistan), 0-6″ depth (Humid)	8.4	5.1	22.8
2. Black Soil from Government Experimental Farm, Akola (Maharashtra, India), 0-9″ depth (Humid)	39.5	7.1	44.8
3. Podsolic Soil from Chaubattia Farm (Uttar Pradesh, India) (Surface) (Humid)	15.2	4.2	26.5
4. Division of Botany, Indian Agricultural Research Institute, New Delhi (India) 0-4″ depth (Semiarid)	13.5	8.4	13.3
5. Ajmer Soil near Ajmer (Rajasthan, India), 0-12″ depth (Arid)	4.25	8.2	4.44
6. Botanical Garden, Agra (Uttar Pradesh, India) (Semiarid)	16.8	7.4	13.6

Note : Data from various sources.

TABLE 7.7
AVERAGE SOIL PROFILE CATION EXCHANGE CAPACITIES, LUZON, PHILIPPINES *

Soil	Average Cation Exchange Capacity m.e./100 gm. Whole soil	Average Cation Exchange Capacity m.e./100 gm. Clay from whole soil
Lipa clay loam, upland	34	68
Carmona sandy clay, upland	36	76
Bigaa clay, lowland	39	64
Bigaa clay, lowland	36	56
Lowland, unclassified	35	73
Lowland, unclassified	22	51
Rugao sandy loam, upland	14	21
Ilagan sandy loam, upland	49	84
Lowland, unclassified	42	67
Lowland, unclassified	29	116

* *Source :* Fernandez, N.C., *Variations in Certain Properties of Ten Soil Profiles Collected in Luzon, Philippines.* In press, 1964. From private communication.

exchange capacity per 100 gm. of soil. The value ranges from approximately 5-10 me/100 gm. of soil for fine sandy loam. For clay loams it is approximately 15-20 m.e., while for clay soils it usually exceeds 30 m.e.

8. AMOUNTS OF EXCHANGEABLE CATIONS IN SOILS

The ratio of the several cations which are attached to the exchange complex varies with the conditions under which the soil has been formed. These ratios can be altered by liming and fertiliser treatment.

In neutral or nearly neutral conditions in temperate climates, calcium commonly forms about 80 per cent or more of these bases, magnesium about 10 to 15 per cent, the remaining bases being chiefly sodium and potassium.

In saline and alkaline soils, sodium is the predominant exchangeable base; soils of humid regions have calcium and hydrogen as the dominant cations. Generally speaking, a soil with a pH of 5.5 may have 50 per cent Ca, 33 per cent hydrogen, and 17 per cent of other cations in its exchange complex.

The average amounts of exchangeable cations in ten soil profiles in Luzon, Philippines, was as follows* :

Cation	Range, milliequivalents per 100 gm. soil
Calcium	2.6 —22.3
Magnesium	0 5 — 7.1
Sodium	0.1 — 3.4
Potassium	0.2 — 1.3

The exchangeable bases are thus in the relative order of Ca > Mg > Na > K, although in a few instances the amount ef exchangeable potassium exceeded that of sodium. On a percentage basis, exchangeable calcium represented from 65 to 83 per cent of the total exchangeable bases, magnesium 12 to 30 per cent, sodium 2 to 12 per cent, and potassium 0.5 to 8 per cent. The same 10 soil profiles under study in the Philippines had a pH range from 4.9 to 6.6.

9. BASE SATURATION AND pH

The pH of soil can be determined accurately and fairly quickly, while the determination of base saturation is time consuming. Fortunately, there is a definite correlation between pH and base saturation for a particuiar soil type. If pH is determined, the base saturation can then be estimated. For

* Fernandez, N.C., *Variation in Certain Properties of Ten Soil Profiles Collected in Luzon, Philippines*. In press, 1964. From private communication.

example if montmorillonite clay has a pH of 6.5 at 90% base saturation, the pH of such a clay is 5, with 65% base saturation. The actual per cent base saturation at a particular pH may vary with different soil types but the determination of relationship between pH and base saturation for a particular type is useful in determining lime requirement of acid soils.

In Luzon, Philippines, the average base saturation in ten soil profiles ranged from 26 to 86 per cent. The average for soils derived from sedimentary rocks was 55 per cent ; for soils from volcanic tuff, 61 per cent ; and for soils of alluvial origin, 68 per cent.

The pH of the surface of the soils varied from 4.9 to 6.6. The average pH of soils from sedimentary rocks was 5.6 ; for volcanic soils, 5.8 ; and for soils of alluvial origin, 6.2. Generally, the pH increased with soil depth. The correlation of pH and base saturation was highly significant.*

10. EXCHANGEABLE CATIONS AND PLANT NUTRITION

Next to photosynthesis, ionic exchange (particularly cation exchange) reactions are the most important chemical reactions in the whole domain of agriculture. In fact several workers have shown that the capacity of soil to exchange cations is the best single index of soil fertility.

The nature and content of exchangeable bases in a soil have an important bearing on its general properties. Soils with a high calcium base saturation are in the most satisfactory physical and nutritional condition. A calcium-dominated soil is granular in structure and porous. Calcium-dominated clay ensures good aeration and good drainage, thus minimising unfavourable effects of a high clay content.

Soils which are base unsaturated have high potential acidity due to exchangeable hydrogen. These soils, though friable, do not support plant growth adequately if the per cent base unsaturation, (exchangeable hydrogen) exceeds 30. Liming is resorted to in such cases.

In arid and semiarid regions, there may be other soils which are fully base saturated but the dominant cation is sodium, as in alkali soils. The Na-clay is deflocculated, sticky, difficult to work, and has poor drainage and poor aeration.

*Fernandez, N.C., *Variation in Certain Properties of Ten Soil Profiles Collected in Luzon, Philippines*. In press, 1964. From private communication.

In all such situations, the attempt of agriculturists is to produce calcium-dominated soils. In the case of alkali soils, calcium domination is obtained by the addition of gypsum, and the leaching out of the resulting sodium sulphate.

The cations Ca, Mg, K, and NH_4 are held on the colloidal surfaces and are readily available to plants. In fact, the method of determining available potassium is based on determining exchangeable potassium. The colloidal clay and humus also adsorb certain amounts of the phosphate anion which is slowly released to plants. Laterite soils have a higher adsorptive and fixation capacity for phosphates than black soils. Thus the colloidal clay and humus hold in an exchangeable and available form varying amounts of the plant nutrients, Ca, Mg, K, N, and P and most of the micronutrients.

Due to the property of base exchange (cation exchange) the soluble inorganic fertiliser nutrients are not washed away from the soil. For example when ammonium sulphate or potassium sulphate are added to the soil, ammonium and potassium ions are held on the surface of colloids by cationic exchange. Exchangeable potassium ions are directly available to plants. Ammonium ions are also released which may be taken up by the plant as such or first nitrified to nitrate and then absorbed by plants. This alone is of great significance. otherwise the leaching losses of available nutrients would be immense and the use of water soluble fertilisers would be of doubtful significance.

The predominance of desirable cations such as calcium in the exchange complex brings about desirable physical conditions and favourably influences the microbial activities, ammonification, and nitrification.

The kinds of cations present in the exchange complex also affect the pH of the soil solution, e.g., a Na-clay is alkaline and a H-clay is acidic. It is well known that pH affects the availability of several nutrients. Strongly acidic soils may have high (perhaps toxic) amounts of available Mn, but phosphate availability is low. (See Chapter 14).

Knowledge of cation exchange helps in reclaiming acidic, saline, and alkali soils.

II. ANIONIC EXCHANGE

Soils, especially those high in organic matter, have the ability to hold a small amount of anions in the exchangeable form. In general the relative

order of anion exchange is:

$$OH^- > H_2PO_4^- > SO_4^{--} > NO_3^-$$

Of these anions the exchangeable phosphate is of most importance since sulphates or nitrates are not retained in appreciable amounts nor for long periods of time.

Phosphates are held in the soil in fairly large amounts and the more acid the soil, the more the phosphates are retained. But most of the adsorption is not exchangeable. In acid soils, iron and aluminium readily form relatively insoluble compounds with the phosphates. However part of the phosphate which has reacted with iron and aluminium compounds and with silicate clays is subject to replacement by other anions such as OH ions. Such replacement is called anion exchange.

Olsen's method of estimation of available phosphate, using $\frac{M}{2}$ $NaHCO_3$ with pH 8.5, employs the principle of anion exchange by OH ions.

Soils having a predominance of kaolinite have higher anion exchange capacity than those with montmorillonite or illite as the chief mineral group.

12. FIXATION OF POTASSIUM

Long-time experiments have shown that there is some mechanism in the soil that fixes available potassium in a form which is not available to plants. The factors influencing the amount of potassium fixation are :

1. The kind of clay minerals present. Kaolinite does not appear to fix potassium, while large quantities are fixed by montmorillonite.
2. The relative amount of exchangeable potassium. The greater the percentage of exchangeable potassium in relation to the total exchange capacity, the greater the potassium fixation.
3. Wetting and drying of the soil. Soils that are wetted and dried fix large amounts of ~~exchangeable~~ potassium. One explanation for this mechanism is that potassium ions move inside the clay-crystal lattice when it is wet and expanded, and, upon drying, the ions are trapped inside. Any soil treatment that would keep the soil more uniform in moisture content, such as shading or the use of a mulch, would therefore tend to reduce potassium fixation.

4. The presence of organic matter. Humus particles exist in the soil in all sizes. Some particles are small enough to enter the clay-crystal lattice and to reduce the amount of contraction upon drying. This mechanism tends to lessen the amount of entrapped potassium.

13. FIXATION OF AMMONIUM*

In recent years it has been demonstrated that approximately 5 per cent of the total nitrogen in surface soils and as much as 60 per cent of the total nitrogen in subsoils is held as nonexchangeable (fixed) ammonium. The mechanism of fixation appears to be the same as that for potassium fixation, i.e., from a replacement by the ammonium ion for interlayer cations such as calcium, magnesium, sodium, and hydrogen, in the expanded lattice of clay minerals (crystals). When ammonium ions replace other cations, the lattice of the clay crystal contracts, entrapping the ammonium ions in a nonexchangeable (fixed) form. The fixed ammonium can be slowly released by cations that expand the lattice, i.e., calcium, magnesium, sodium, and hydrogen. Potassium contracts the lattice and therefore does not replace the fixed ammonium. The total amount of fixed ammonium in a soil is directly related to the amount and kind of clay present; the more the clay the more the fixed ammonium, and the more the percentage of clay present that is of the expanding lattice type (montmorillonite) the more the fixed ammonium. Soils containing kaolinite clay and illite with a nonexpanding lattice, exhibit less fixed ammonium.

Work on ammonium fixation on soils of Madhya Pradesh, India** has shown that the ammonium fixing capacity ranges from 0.55-2.0 m.e. per 100 gm. of soil, while that of the clay fraction ranges between 1.45-4.5 m.e. per 100 gm. of clay. The highest fixing capacity is shown by black soils and alluvial soils. Black soils are known to be rich in the montmorillonite type of clay minerals.

The naturally fixed ammonium comprises 27-71 per cent of the fixing capacity. The naturally fixed ammonium forms a significant part of total soil nitrogen, being 16-20 per cent in surface soils and up to 66 per cent in subsoils.

**Source*: Soil Science Proceedings, Vol. 23, No. 2, 1959, pp. 121-124.

**Tiwari A.K., *Ammonium Fixation in Soils of Madhya Pradesh*. M. Sc. (Ag.) Thesis, Vikram University, Ujjain, Madhya Pradesh, India. 1961.

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CHAPTER EIGHT

SOIL REACTION AND BUFFERING

Edmund Ruffin of Virginia, U.S.A., in 1832 published, *An Essay on Calcareous Manures*, in which he explained that sour soils contain insoluble acids and that the function of calcareous manures was to neutralise these acids.

Soil reaction is the most important single chemical characteristic influencing many physical and chemical properties of the soil. Suitability of soil as a medium for the growth of plants and desirable microorganisms depends upon whether the soil is acid, neutral, or alkaline.

I. METHODS OF EXPRESSING ACIDITY AND ALKALINITY

When dissolved in water, an acid will dissociate and release hydrogen ions, H^+, which makes the solution acid. Similarly, when an alkali is dissolved in water, it produces hydroxyl ions, OH^-, which makes the solution alkaline. Although equivalent quantities of all acids, contain the same amounts of *total* hydrogen, when dissolved in water the hydrogen in them does not ionise to the same extent. For example, hydrochloric acid dissociates completely in water; whereas under similar conditions, acetic acid dissociates only approximately 10 per cent. Consequently in a normal solution of hydrochloric acid there will be one gram of $[H^+]$, whereas in a normal solution of acetic acid there will be only one tenth of a gram of $[H^+]$, per litre of solution. In titration, 10 ml. of decinormal hydrochloric acid and 10 ml. of decinormal acetic acid will each require 10 ml. of decinormal sodium hydroxide for neutralization, since the *total acidity* is the same. If hydrochloric acid and acetic acid solutions are separately applied near plant roots, the hydrochloric acid will cause greater damage to the plant because of the greater number of ***hydrogen ions*** in the decinormal hydrochloric acid

solution. The number of hydrogen ions in decinormal hydrochloric acid is almost 70 times larger than the number of hydrogen ions in decinormal acetic acid. Thus the titration determines both ionized and un-ionized hydrogen, i.e., it gives expression to the *total* hydrogen involved. On the other hand, the ionized hydrogen (hydrogen ion concentration) gives expression only to the *intensity* factor.

Acids are called weak or strong depending upon the degree of ionisation. The greater the ionisation, the larger the number of hydrogen ions in solution and the stronger the acid. Thus hydrochloric acid is a strong acid while acetic acid is a weak acid, even though the titratable acidity (total acidity) in the two acids may be same.

In order to understand soil acidity, the fundamentals of hydrogen ion concentration and pH will first be discussed. Water is dissociated into hydrogen ions and hydroxyl ions:

$$H_2O \rightleftharpoons H^+ + OH^-$$

This reaction proceeds to the right only to a very slight extent because the water molecule is very stable. At any one time, only about one water molecule in 10 million is ionized. The extent to which water ionises can be expressed in terms of an ionisation constant, Kw.

$$Kw = [H^+]\,[OH^-]. \qquad \text{(Equation A)}$$

$[H^+]$ and $[OH^-]$ are the concentrations of hydrogen ions and hydroxyl ions, expressed as equivalents per liter. One equivalent of a singly charged ionic species is the weight in grams of that species, which contains 6.023×10^{23} particles.

The value of Kw is 10^{-14} at 22°C., and in any aqueous system at this temperature the product of the concentrations of hydrogen and hydroxyl ions is 10^{-14}.

Equation A can be written in a more useful form by dividing both sides into 1 and taking logarithms. That is:

$$\log \frac{1}{Kw} = \log \frac{1}{[H^+]} + \log \frac{1}{[OH^-]} = 14 \qquad \text{(Equation B)}$$

The values of log $1/[H^+]$ and log $1/[OH^-]$ generally are referred to as pH and pOH, respectively. These values are indices of the acidity or alkalinity of a system.

Any system in which pH and pOH are equal is neutral. At 22°C.,

when $Kw=10^{-14}$, neutrality corresponds to pH=pOH=7. When pH is less than 7, the system is acid. When pH is above 7, it is alkaline.

Soils vary in pH from about 4, for strongly acid soils, to about 10, for alkaline soils that contain free sodium carbonate.

The pH range for most agricultural soils is 5 to 8.5.*

2. HYDROGEN ION CONCENTRATION AND PH

Freshly distilled water contains the same number of H^+ and OH^- ions; it is therefore netural. Add $Ca(OH)_2$ to the neutral water and there will be more OH^- than H^+; then the water will be alkaline. Conversely, when HCl is added to the neutral water it will contain more H^+ than OH^-, and water will become acidic.

The most convenient method of expressing the relationship between H^+ and OH^- is pH. By pH is meant the logarithm of the reciprocal of the hydrogen-ion concentration in grams per liter, usually written :

$$pH = \log \frac{1}{[H^+]}$$

At neutrality, the hydrogen-ion concentration is :

0.000 000 1 or 1×10^{-7} grams of hydrogen per litre of solution.

Substituting this concentration into the formula :

$$\begin{aligned} pH &= \log \frac{1}{0.000\ 000\ 1} \\ &= \log 10{,}000{,}000 \\ &= 7 \end{aligned}$$

At a pH of 6, there is 0.000 001 gram of active hydrogen, or 10 times the concentration of H^+ than at a pH of 7. At each smaller pH unit, the $[H^+]$ increases by 10 in concentration. It therefore follows that a pH of 6 is 10 times more acid than a pH of 7; a pH of 5 is 10 times more acid than a pH of 6, and so on.

The pH concept permits the expression of the hydrogen ion concentration on a scale of acidity and alkalinity from 0 to 14.

The relationship between the hydrogen ion concentration $[H^+]$ and pH for the entire range of pH 0-14, is given in Table 8.1.

* *Source : The 1957 Yearbook of Agriculture.* United States Department of Agriculture, Washington, D.C.

TABLE 8.1
THE RELATIONSHIP BETWEEN HYDROGEN ION CONCENTRATION [H+] AND pH

[H+]	pH
1×10^{-0}	0
1×10^{-1}	1
1×10^{-2}	2
1×10^{-3}	3
1×10^{-4}	4
1×10^{-5}	5
1×10^{-6}	6
Neutral 1×10^{-7}	7
1×10^{-8}	8
1×10^{-9}	9
1×10^{-10}	10
1×10^{-11}	11
1×10^{-12}	12
1×10^{-13}	13
1×10^{-14}	14

3. BUFFER ACTION

Buffering refers to resistance to a change in pH. If 1 ml. of 0.01N HCl is added to one litre of pure distilled water of pH 7.0, the resulting solution would have a pH of about 5.0. If on the other hand, this same amount of acid is added to a litre of *soil* suspension the resulting change in pH would be very small. The soil suspension is buffered against a change in pH.

In effecting a certain change of pH in soil, it is usually necessary to add much more acid or alkali than the amounts of H^+ and OH^- ions in the soil suspension would lead us to expect. There is, thus, a distinct resistance to a change in pH. This power to resist a change in pH is called buffer action and in soils is due primarily to the influence of the exchange complex that reacts similar to weak acids and their salts. At a pH above about 8.0, buffering is due partly to the decomposition of minerals.

A buffer solution is one which contains reserve acidity and alkalinity and does not change pH with small additions of acids or alkalis. For a clearer understanding, a simple example of acetic acid and its salt, sodium acetate, will be discussed. When a weak acid such as acetic acid is added to water, complete dissociation does not occur. Most of the hydrogen remains in molecular form and the solution contains CH_3COOH molecules as well as a small concentration of H^+ and CH_3COO^- ions.

If a small quantity of strong alkali like NaOH is added, it will dissociate into Na^+ and OH^- ions. Thus H^+, OH^-, Na^+, and CH_3 COO^- ions will be present in solution. Since water (HOH) ionises to a very small degree, H^+ and OH^- ions exist in solution only in small amounts. The OH^- ions combine with H^+ ions to form molecular water. As there is a larger portion of undissociated acetic acid in solution, more of it will dissociate into hydrogen and acetate ions to restore the equilibrium among undissociated acid and hydrogen and acetate ions. Thus the concentration of hydrogen ions will remain practically the same and little change in pH will take place. The acetic acid solution is buffered against an alkali to such an extent that considerable amounts must be added to effectively raise the pH.

If sodium acetate is added to the acetic acid solution, above, it will be buffered against acid also. In such a solution, the dissociation of acetic acid is small but the dissociation of sodium acetate is large.

Now if a small quantity of strong acid such as HCl is added, it is immediately and largely dissociated into H^+ and Cl^- ions. Thus in the solution H^+, Cl^-, Na^+ and CH_3COO^- ions are now present.

Acetic acid ionises to a small degree and as it is already maintaining its maximum dissociation, H^+ and CH_3COO^- ions cannot exist in solution to a large extent and are converted into molecular acetic acid. The large part of H^+ ions from HCl will combine with CH_3COO^- ions to form undissociated acetic acid, and the hydrogen ion concentration (pH) of the solution will be slightly affected. The titration would of course show an increase in acidity. Likewise, a solution of ammonium acetate and acetic acid or salts of phosphoric acid (phosphates) act as a buffer against both acids and alkalis. Buffer action is thus due to the influence of weak acids and their salts.

4. BUFFERING IN SOILS

Soils also exhibit buffering action. In order to produce a certain change of pH, it is usually necessary to add much more acid or alkali than the amount of H^+ and OH^- ions in the soil suspension would lead us to expect. This buffering action (i.e., resistance to change in pH) is due to the influence of weak acids and their salts. Carbonates, bicarbonates, and phosphates are present in soils and act as buffering agents. More important than this, the colloidal complex with associated cations acts as a strong buffering agent. Organic acids are continually being formed in soil as a result of microbial activity. These acids are weak acids and provide excellent buffering agents. Similarly the colloidal complex (both organic

and inorganic) can be represented as being made up of a negative acidoid with adsorbed cations. In humid and subhumid regions, calcium and hydrogen cations are the most numerous of the adsorbed ions. Their probable dissociation is represented as follows :

$$\text{H (acidoid)} \rightleftharpoons \text{(acidoid)} + H^+$$

$$\text{Ca (acidoid)} \rightleftharpoons \text{(acidoid)} + Ca^{++}$$

H^+ ions are released slowly from the exchange complex and provide reserve (potential) acidity. As soon as H^+ ions of soil solution (active acidity) is neutralised by alkaline substances, more of hydrogen ions are released, thus effecting little change in pH.

If any acidic substance is added to a soil, H^+ ions from the acid readily combine with the exchange complex, displacing Ca^{++} ions and removing H^+ ions from soil solution. Thus, little change in hydrogen ion concentration (pH) of the soil solution takes place. The colloidal complex is similar to a mixture of weak acids and their salts, and it functions as a buffer exactly in the same way as does an acetic acid-sodium acetate solution. The basis of buffer capacity in soil lies in the reserve hydrogen of the exchange complex and its associated metallic cations.

5. BUFFER CAPACITY AND BUFFERING CURVES

If varying amounts of acid or alkali are added to a given suspension of soil in water and the pH determined after equilibrium has been attained, it is possible to obtain buffering curves. Ten gram portions of soil are shaken in flasks, each containing 30 ml. of water, to which varying amounts of N/25 HCl and $Ca(OH)_2$, respectively, had been added. After allowing them to stand for 24 hours with frequent shaking, the pH is determined electrometrically. The buffering capacity for fine soil of Madhya Pradesh, India is shown in Figure 8.1.

The curve labelled "water" in Figure 8.1 represents a blank experiment without soil. The divergence of an individual buffering curve from this curve gives a measure of the interaction between the soil and the acid or alkali. The curves for clay loam or clayey soils show considerable divergence from the blank curve with water. The larger the buffering capacity, the greater the tendency for the curve to be horizontal.

Soils show buffering both on the acid and alkaline side. They are said to be amphoteric, *i.e.*, exhibiting both basic and acidic properties. This is due to the fact that the colloidal complex contains both acidoid (acid-like) and basoid (base-like) components.

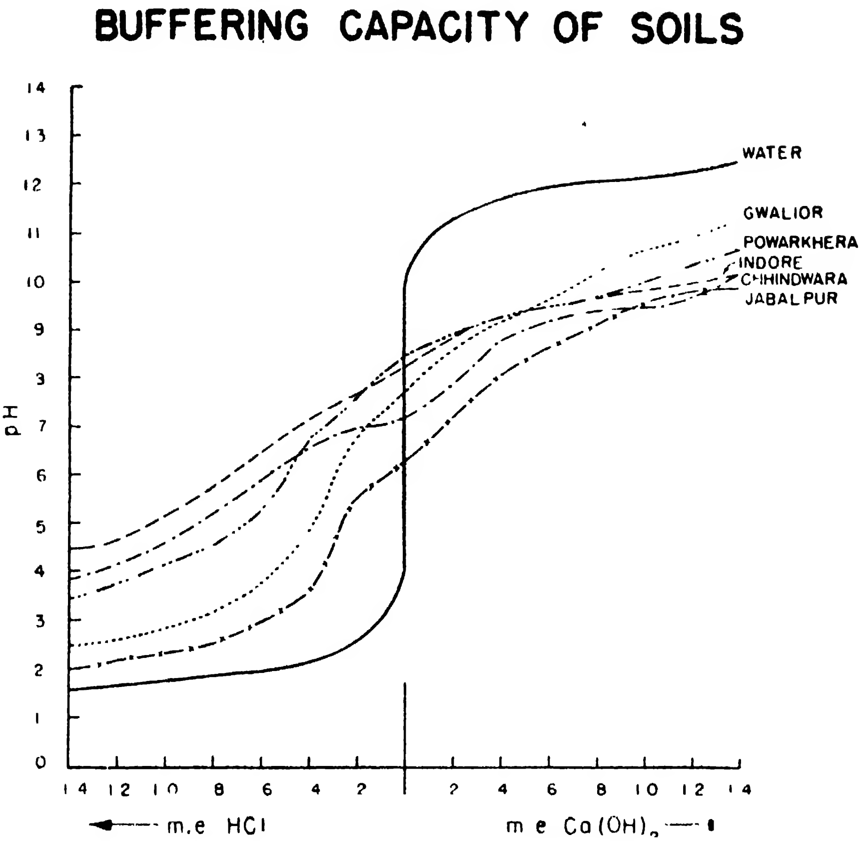

Fig. 8.1 Buffering curve of water in comparison with the buffering curves of some contrasting soils from Madhya Pradesh, India (*Source : H. H. P. Agarwal and D. P. Motiramani*). *Note* : The clay and sand precentages of the soils are :

Soil Location	Clay %	Sand %
Jabalpur	14	70
Gwalior	20	44
Powarkhera	42	30
Chhindwara	48	22
Indore	56	10

In general it can be said that the buffering capacity of soils depends upon the reactive amounts and kinds of colloidal material present. Other factors being equal, the higher the exchange capacity of the soil, the greater will be its buffer capacity. Thus an acid soil with high amounts of clay and/

or organic matter will require larger amounts of lime for affecting a certain change in pH than an acid soil with smaller amounts of clay and/or organic matter.

6. IMPORTANCE OF BUFFERING TO AGRICULTURE

The significance of soil buffering to agriculture is mainly two-fold :

(1) The stabilization of soil pH, and

(2) The amounts of amendments necessary to affect a certain change in soil reaction.

A sudden change in pH causes a radical modification in soil conditions and if this environment should fluctuate too widely, as might be the case with an unbuffered medium, higher plants and microorganisms would suffer seriously. Changes in soil reaction not only have a direct influence on the plants but also exert an indirect influence on soil environment by creating sudden changes in the availability of nutrients. Deficiencies of certain plant nutrients and excesses of others in toxic amounts would seriously upset the nutritional balance in the soil. Changes in soil pH should be made gradually and at a time of the year when the biological upset is likely to be least serious, such as during a period when no crop is growing.

The amounts of amendments necessary to affect a given alteration in soil reaction also relates to the effectiveness of pH stabilization. The greater the buffering capacity of the soil, the larger must be the amounts of lime or sulphur to affect a given change in pH. Although pH gives some idea as to the active acidity or alkalinity, and to a certain extent the base saturation, it gives no idea of the buffering capacity of the soil. The buffering capacity depends mainly on the amount and nature of clay and the organic matter content. Hence, in deciding on the amount of lime to apply for any given pH, soil texture, soil type, and organic matter content are practical guides.

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CHAPTER NINE

ACID SOILS

" *They manured their fields with a white chalk which they dug out of the ground*".

VARRO, 116-28 B. C.

Soils are acid for one or more of the following reasons :

(1) Leaching due to heavy rainfall,
(2) Origin of soil from acid parent material,
(3) Use of acid-forming fertilisers, and
(4) Microbiological action.

Leaching due to heavy rainfall : The magnitude of leaching is the main factor involved in determining whether or not the soil formed will be acid. The rainfall carries lime and other bases downward beyond the reach of plant roots. Humid regions are the most susceptible to acid soil formation unless there is a large accumulation of $CaCO_3$ present in the soil. Thus, countries having an annual rainfall of 100 cm. (40 inches) or more have a high percentage of acid soils. Rain water containing dissolved carbon dioxide from air or from soil is particularly effective in dissolving and leaching calcium from the soil.

Origin of soil from acid parent material : Some soils have developed from parent materials which are acid, such as granite. Here too, the leaching effect is predominant in creating acidity.

Use of acid-forming fertilisers : The use of ammonium sulphate and ammonium nitrate have long been known to increase soil acidity. Ammonium ions from ammonium sulphate when added to the soil replace calcium (the dominant cation) from the exchange complex and the calcium sulphate formed is liable to be lost in leaching. For example 109 kilograms of $CaCO_3$ are required to neutralize the acidity developed in the soil by the use of 100 kilograms of ammonium sulphate fertiliser.

The lime requirement for such acid fertilisers is met from the reserve $CaCO_3$ in the soil. If the soil contains no free lime, the soils would turn

acid with constant use of fertilisers like ammonium sulphate or ammonium nitrate. (Table 9.1).

TABLE 9.1
THE COMMON NITROGENOUS FERTILISERS AND THEIR ACIDITY OR BASICITY

Material	N per cent	Equivalent Acidity*		Equivalent Basicity**	
		Per Pound of N	Per 100 Pounds of Material	Per Pound of N	Per 100 Pounds of Material
Calcium Ammonium Nitrate	20.5	Physiologically neutral in reaction			
Urea	46.0	1.6	74		
Ammonium sulphate nitrate	26.0	3.6	93		
Ammonium chloride	25.0	5.1	128		
Ammonium sulphate	20.6	5.2	109		
Sodium nitrate	16 0			1.8	29

*Equivalent acidity refers to the pounds of pure calcium carbonate required to neutralise the acids produced in the soil from the quantity of fertiliser indicated.

**Equivalent basicity refers to the pounds of pure calcium carbonate equivalent to the alkalinity produced in the soil from the quantity of fertiliser indicated.

Microbiological action : Several kinds of microorganisms are active in the soil. These are responsible for many processes such as decomposition of organic residues and nitrification. As a result of microbial activity, acids are constantly being formed. These, on liberation, seek a base either from free $CaCO_3$ or from the exchange complex. If the exchange complex is low in base saturation, these acids are not neutralized and cause the soil solution to be acid.

I. SOIL pH AND NUTRIENT AVAILABILITY

The general relationship between soil pH and plant nutrient availability is shown in Figure 9.1. From this chart it is obvious that the range of maximum availability of the primary nutrients—nitrogen, phosphorus, and potassium, as well as the secondary nutrients—sulphur, calcium, and magnesium, is at a pH range of 6.5 to 7.5.

The availability of the minor elements—iron, manganese, boron, copper, chlorine, and zinc is more in the acid range than in the neutral or alkaline range. Since the requirement of plants of these minor nutrients is

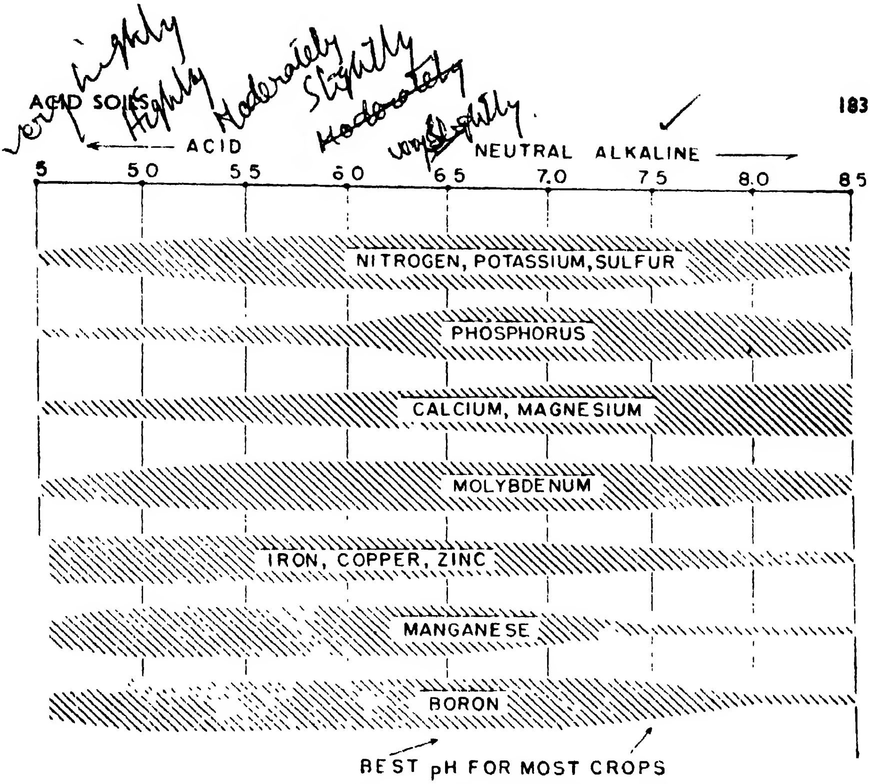


Fig. 9.1 The relationship between soil pH and the relative availability of plant nutrients. The wider the bar, the greater the availability. *(Redrawn from Truog.)*

small, the quantities available at pH 6.5-7.5 are usually enough for satisfactory plant growth.

Boron deficiency frequently occurs when too much lime is added to an acid soil. On the other hand molybdenum is not often deficient in acid soils but becomes more available as the soil is limed

A pH of from 6.5 to 7.5 is therefore considered to be the pH range in which most soil nutrients are available to plants. Commercial fertilisers are also most readily available in this pH range.

The lime requirement depends upon the following factors :

The pH of the soil : More lime is needed for strongly acid soils than for weakly acid soils. (Table 9.2).

Texture and organic matter content : Although pH gives some idea as to the lime requirement, it reveals nothing about buffer capacity. Hence in deciding as to the amount of lime necessary, soil texture and organic matter content are practical guides and should not be overlooked. Clay and organic matter increase the cation exchange capacity and buffer capacity. For a

TABLE 9.2

SCALE OF LIME REQUIREMENT BY THE BUFFER METHOD*

Soil Buffer pH	Lime Requirement Tons of pure $CaCO_3$/Acre	Soil Buffer pH	Lime Requirement Tons of pure $CaCO_3$/Acre
6.7	1.6	5.7	7.6
6.6	2.2	5 6	8.2
6.5	2.8	5.5	8.9
6.4	3.4	5.4	9.5
6.3	4.0	5.3	10.1
6.2	4.6	5.2	11.0
6.1	5.2	5.1	11.7
6.0	5.8	5.0	12.4
5.9	6.4	4.9	13.2
5.8	7.0	4.8	14.0

Source : Shoemaker, H. E., McLean, E.O , and Pratt, P.F , *Buffer Method for Determining Lime Requirement of Soils with Appreciable Amounts of Extracted Aluminium.* Proc. Soil Science Society of America ; 25, 274, 1961.

Note : The indicated amounts of lime are sufficient to increase the soil pH to 6.8.

particular pH, a sandy soil will require less lime than a clay loam. The relationship between lime requirement and texture is shown in Figure 9.2. Sands and sandy loams require approximately 1 to 1½ tons of limestone to effect a change of soil pH one unit—say from 5.5 to 6.5; and a silt loam and clay loam require approximately 2 tons.

TABLE 9.3

RECOMMENDED DOSES OF LIMESTONE FOR DIFFERENT SOIL TEXTURAL CLASSES IN PUNJAB, INDIA

Soil pH	Pounds of Limestone required per acre for different soil textural classes		
	Sandy loam	Loam	Clay loam
5.0	1,125	1,687	2,625
5.2	975	1,462	2,275
5.4	825	1,237	1,925
5.6	675	1,012	1,575
5.8	525	787	1,225
6.0	375	562	875
6.2	225	337	525

Source : Kanwar, J. S., and D. R. Bhumla, *Indian Farming* 9 (2): 27-28, New Delhi, India. (1959)

Type of clay : There is also a variation in lime needs depending upon the type of clay present as well as the range of the pH desired. As the desired pH range comes closer to 7.0, the amount of lime required to effect the same pH change is greater. For example, it takes about 20 per cent more lime to change the soil pH from 5.5 to 6.5 than it does to change it from 4.5 to 5.5.

The lime requirements of a large number of acid soils in Punjab have been determined and the data is given in Table 9.3. The effect of texture is clearly predominant.

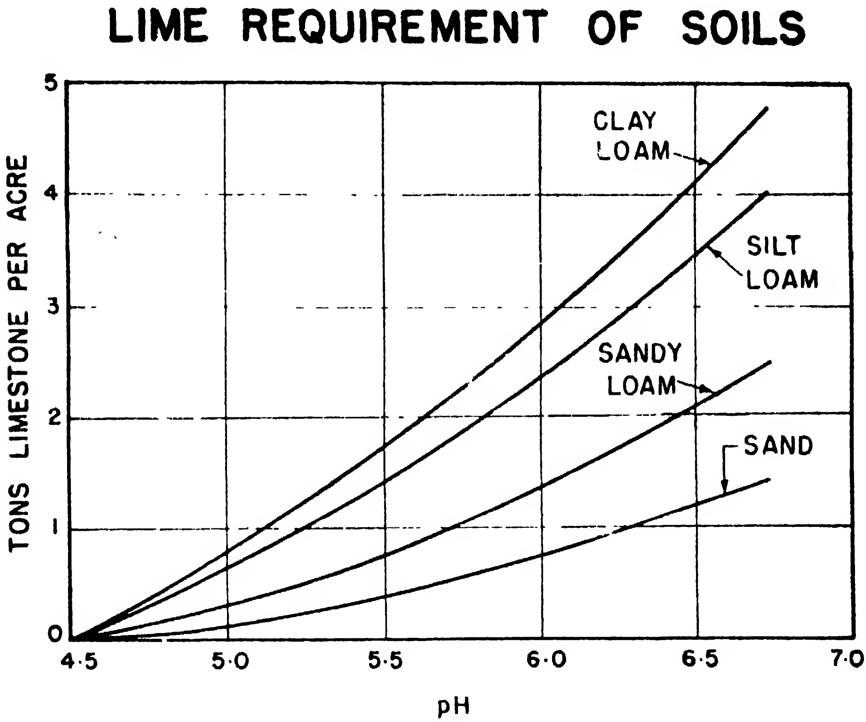


Fig. 9.2 Approximate tons of limestone required for each of four soil textural classes to increase the pH from 4.5. to 6.8. (*Source : U.S.D.A. Farmers' Bulletin No. 2124, 1959.*)

Lime is added to acid soils primarily for three purposes.

1. To supply calcium and sometimes magnesium as a plant nutrient.
2. To reduce the toxicity of aluminium, manganese and iron.
3. To increase the pH of acid soils and thereby make other plant nutrients more available.

The acidic soils in Tropical Asia, as elsewhere, are located in areas of heavy rainfall. Luzon, Philippines, reports a surface soil pH range of 4.9

to 6.6. The acidic soils in India are located in Kerala, Assam, Manipur, Tripura, some districts of West Bengal, Bihar and Orissa. In Madhya Pradesh, acid soils are observed in Bastar district. In Maharashtra, acid soils are found in Kolaba, Ratnagiri, Chanda, and Bhandara districts. In Punjab, acid soils are found in Kangra district and part of Gurdaspur, Hoshiarpur and Patiala districts. Salem district of Madras and Ponnampet and Shimoga districts of Mysore also have acidic soils.

2. EFFECTS OF SOIL ACIDITY ON PLANTS

The various effects exerted on plants by soil acidity may be direct or indirect. Direct influences are: (a) toxic effects of H ions on root tissues; (b) influence of soil acidity on the permeability of the plant

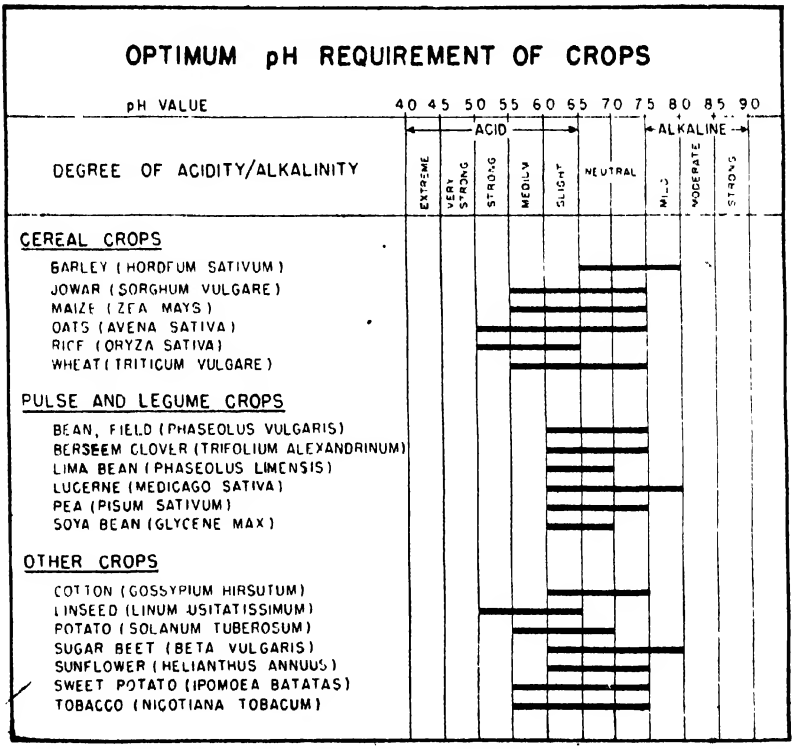


Fig. 9.3 The optimum pH for most crops is between 6.5 and 7.5. Oats, rice and linseed, however, grow well at a pH as low as 5.0, while barley, lucerne, and sugar beet produce normally at a pH as high as 8.0. (*Source: Ignatieff, Vladimir, and Page, Harold J., The Efficient Use of Fertilisers, F.A.O., Rome, Italy, 1958.*)

membranes for cations ; and (c) disturbance in the balance between basic and acidic constituents through the roots.

The soil acidity undoubtedly exerts direct harmful effects on plants particularly by affecting the enzymic changes since the enzymes are particularly sensitive to pH changes. It is, however, increasingly being believed that it is the soil conditions created by the acidity which are harmful to plants. The optimum pH requirement of selected crops is shown in Figure 9.3.

Rice, oats, and linseed can tolerate a fairly acid reaction (pH 5.0) while barley, sugar beet, and lucerne can tolerate a fairly alkaline reaction (pH 8.0).

Indirect influences are:

(a) Availability of various nutrients, e.g., phosphorus, copper, and zinc.

(b) High solubility and availability of elements like aluminium, manganese, and iron in toxic amounts due to high soil acidity.

(c) Beneficial activities of soil microorganisms adversely affected.

(d) Prevalence of plant diseases.

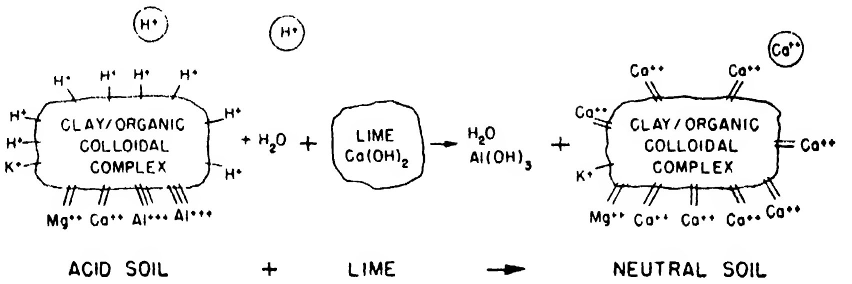
(e) Due to soil acidity, nutrients such as calcium and potassium may be deficient.

3. CORRECTION OF SOIL ACIDITY

Soil acidity is the result of the accumulation of a predominance of H ions over OH ions. The bulk of H ions are held in close association with the clay/organic colloidal complex. When lime is added to moist soil, the soil solution becomes charged with calcium ions. These active Ca ions exchange places with hydrogen ions in the exchange complex. Hydrogen combines with OH ions to form neutral water, or with CO_3 or HCO_3 to form unstable $H_2\,CO_3$, which is readily changed to H_2O and CO_2. (See Figure 9.4.)

A simple and accurate method for measuring the lime requirement may be obtained by constructing a buffer curve. The method has been described under "Buffer Capacity and Buffering Curves", Chapter 8, Section 5. A simple calculation for lime requirement would be as follows : The pH of the soil to which no acid or base was added is 5.0, and it is desired to raise the pH by 1 unit, i.e., to 6.0. If the amount of base to raise the pH from

CATION EXCHANGE REACTIONS WHEN AN ACID SOIL IS LIMED



(H+) Hydrogen ion in soil solution (Active acidity)

H+ Replaceable hydrogen ion (Potential acidity)

(Ca++) Calcium in soil solution

Ca++ Replaceable calcium ion

Mg++ Replaceable magnesium ion

Al+++ Replaceable aluminum ion

K+ Replaceable potassium ion

H_2O Water

$Al(OH)_3$ ALuminum hydroxide

Fig .9.4 When an acid soil is limed, the exchangeable hydrogen on the clay/organic colloidal complex and the hydrogen ions in the soil solution are replaced by calcium. The adsorbed aluminium is also replaced by calcium. (*Source : The 1957 Year Book of Agriculture, United States Department of Agriculture, Washington, D.C.*)

5.0 to 6.0 (from the buffering curve) is 0.15 m.e. for 10 gm. soil, the lime requirement is :*

Lime requirement (as lbs. of pure Ca CO_3/acre) $=$ m.e. base for 10 gm. soil $\times 10 \times 50 \times 20$

$=$ m.e. base for 10 gm. soil $\times$ 10,000.

$=$ $0.15 \times 10{,}000 = 1{,}500$ lbs. $CaCO_3$/acre.

Other methods have been used to determine the lime requirement of soils. The basis of the methods is that a known quantity of soil (usually 10 gm.) is shaken with a buffer solution, after shaking to attain equilibrium, the pH of the suspension is determined. From the pH value of this mixture, the amount of lime to be added to an acre of land can be calculated.

A buffer method has been suggested by soil testing workers. In this method 10 gm. of soil are shaken with 20 ml. of buffer solution

*NOTES : m.e. base for 10 gm. soil is multiplied by 10 for 100 gm. soil. Further multiplication with 50 is made to convert m.e. into mgm. $CaCO_3$ per 100 gm. soil.

Mgm. $CaCO_3$ per 100 gm. soil is multiplied by 20 to convert into lbs. $CaCO_3$ per acre, assuming the weight of an acre furrow slice of the soil to be 2,000,000 lbs.

(containing 1.8 gm. nitrophenol, 2.5 ml. triethanolamine, 3 gm. potassium chromate, 2 gm. Ca acetate and 53.1 gm. of $CaCl_2$ in 800 ml. of water. The pH is adjusted to 7.5 with dilute NaOH or HCl and the solution is made up to 1000 ml). The soil buffer suspension is shaken for 10 minutes on a mechanical shaker and the pH of the suspension is determined. The lime requirement is calculated from the pH of soil-buffer solution suspension. The scale is given in Table 9.2, page 184.

4. WHAT LIME DOES IN THE SOIL

Strongly acid soils are not productive soils. To increase the productivity of acid soils, liming is the first step, for these reasons :

1. Lime makes phosphorus more available. This is true mainly because in acid soils phosphorus is fixed by soluble iron and aluminium. Liming reduces the solubility of iron and aluminium, and therefore less phosphorus is held in these insoluble and unavailable forms.

2. Lime makes potassium more efficient in plant nutrition. When it is plentiful all plants absorb more potassium than they need. Lime reduces the excessive uptake of potassium. Nutritionally and economically, this is a sound practice. When lime is abundant, plants take up more calcium and less potassium. Since calcium is usually deficient in animal rations and potassium is in excess, it is desirable to increase the percentage of calcium in the plant. Economically the practice of liming is desirable because the plant absorbs more cheap calcium and less of the expensive potassium.

3. Lime increases the availability of nitrogen by hastening the decomposition of organic matter.

4. Lime furnishes calcium and magnesium (if the lime is dolomitic) for plant nutrition. These are two of the 16 elements essential for plant growth.

5. Beneficial soil bacteria are encouraged by adequate supplies of lime in the soil.

6. Harmful aluminium, manganese, and iron are rendered insoluble and harmless when a soil is well supplied with lime.

7. Over a period of years a good liming programme improves the physical condition of the soil by decreasing its bulk density, increasing its infiltration capacity, and increasing its rate of percolation of water. Figure

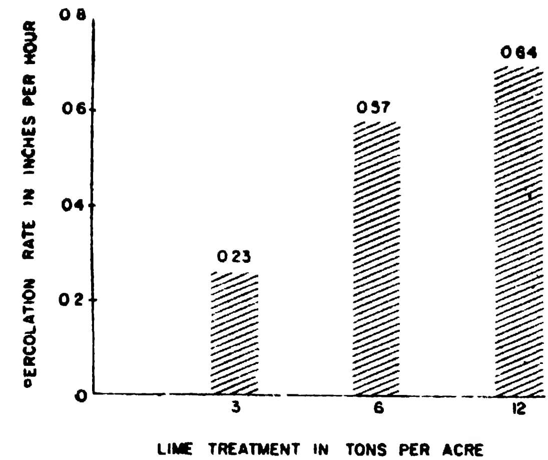


Fig. 9.5 The relationship between the amount of lime applied and the rate of percolation. *(C A. Van Doren and A. A. Klingebiel, "Effect of Management of Soil Permeability". Soil Science Society of America Proceedings, 16, 1952.)*

9.5 presents information showing that the more the lime applied, the greater is the rate of percolation of water through soil. (See Figure 9.5.)

8. There is less soil erosion following an adequate liming program. This result is due primarily to the increased vigour and density of plants following the application of lime and to the increased water infiltration capacity which reduces run-off and increases the amount of water available to crops.

5. CROP RESPONSE TO LIME

The use of lime on acid soils increases the yield of most crops. Legumes greatly and sugar cane appreciably respond to lime application in Taiwan. Lowland rice responds appreciably when the nitrogen supply is small. In simple field experimental plots in Taiwan, it was found that 3 tons of lime per hectare as a basal dressing increased the yield of rice grain in 95 per cent of the plots. In 50 per cent of the cases in Taiwan, the increase was over 10 per cent. In Taiwan the experiments have shown that liming is generally to be recommended for soils with a pH below 5.5.

In Ceylon the application of 6 tons per acre of slaked coral lime or 8 tons per acre of ground coral lime on acid, brown clay loam, lateritic soils has resulted in increased yields of 16 bushels per acre (over 1200 kg/hectare). In Philippines, a considerable area is acidic and liming is more usual with sugar cane, coconut, and legumes.

Experiments done at Ranchi (Bihar, India) have shown that when soils are strongly acid (pH 5.3 to 5.6), lime application substantially increased the yields of maize, wheat, gram, soyabean and groundnut. Table 9.4 and Figure 9.6 show the effect of liming in the presence and absence of fertilisers. The response to liming on *jowar*, *moong*, *arhar*, *masoor*, *marua*, cotton, pea, barley, linseed, and mustard was also encouraging.

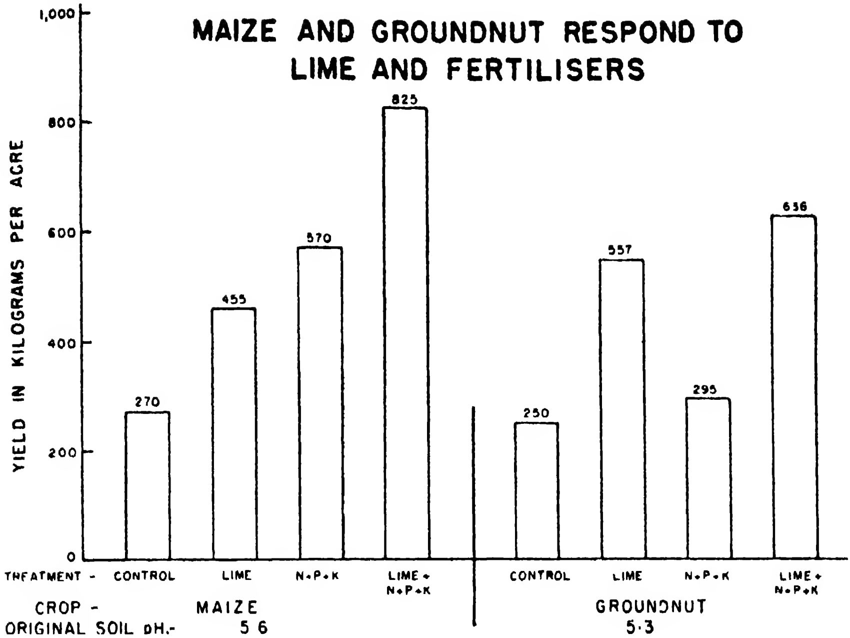


Fig. 9.6 – Maize and groundnut in the Punjab State, India, respond to lime alone but more to lime plus N + P + K fertilisers, when the original pH ranged from 5.3 to 5.6. (For source of data and other details see Table 9.3.)

TABLE 9.4

AVERAGE YIELD OF CROPS DURING 1958-60 FOR DIFFERENT TREATMENTS ON THE UPLANDS OF RANCHI, BIHAR*

Treatment	Crop and Original Soil pH				
	Maize pH 5.6	Wheat (¹) pH 5.6	Gram pH 5.5	Soyabean pH 5.3	Groundnut pH 5.3
	Kilograms per acre				
Control	270	253	71	64	250
Lime (2)	455	318	170	345	557
NPK (3)	570	416	174	136	295
NPK+Lime	825	580	408	547	636

(¹) Average yield of three years (1957-60).

(²) Lime (30% Ca) applied per acre : 1,091 kg (2400 lb.) to soil with pH 5.6 and 1,636 kg (3,600 lb.) for pH 5.3.

(³) NPK for legumes : N=4.5 kg, P_2O_5 and K_2O 18.18 kg. of each per acre per year, for every crop.
NPK for non-legumes : N, P_2O_5, and K_2O, 18.18 kg. of each nutrient per acre per year, for every crop.

**Source* : Chakraborty, M., Chakravarti, B., and Mukherjee, S. K., *Liming in Crop Production*. Bull. 7 Indian Soc. Soil Sci. New Delhi, India. 1961.

Liming of acid soils resulted not only in increased crop production but also in the increased uptake of phosphate. This uptake of phosphate further increased when phosphate fertiliser along with nitrogen and potassium fertiliser were applied to the soil. (See Figure 9.6.)

Experiments in Jagdalpur (Madhya Pradesh, India) have proved the necessity of liming acid soils of Bastar district for increasing crop production. In 1960, 1000 to 1500 pounds of lime in combination with 20 pounds of nitrogen per acre gave 3,268 pounds of paddy per acre and the control (no fertiliser and no lime) was 1,694 pounds of paddy.*

Application of lime at the rate of one to two tons per acre increased the yield of paddy by about 250 kg. per acre in Ponnampet and Shimoga (Mysore, India). On the acid soils of Ponnampet and Shimoga, the effect of lime as a soil amendment has been studied in combination with 3 levels each of nitrogen and phosphorus. The average response to the levels of lime is shown in Table 9.5.

TABLE 9.5

LIME INCREASES PADDY YIELDS ON ACID SOILS

Location	Year	Yield without lime	Increase in yield at different levels of lime		
			½ ton/acre	1 ton/acre	2 tons/acre
		Kilograms per acre			
Ponnampet, Mysore, India	1954–55	1040	67	353	
	1955–56	1170	112	185	
Shimoga, Mysore, India	1954–55	893		92	229
	1955–56	941		162	229

Source: *Fertiliser Trials on Paddy*, I.C.A.R. Research Report No. 1, 1959, New Delhi, India.

Note: All plots received nitrogen (N) and phosphorus (P_2O_5) at 9.09 and 18.18 kg/acre, respectively.

At Ponnampet, there was a good response to lime at the rate of one ton per acre in both years (1954-55 and 1955-56). The dose of 1/2 ton per acre was too small to bring out a significant response. At Shimoga there was significant response in both the years, the response increasing with increased level of lime.

**Proceedings of the Meeting of Agronomy & Soil Science Sub-Committee of Madhya Pradesh Research Committ*, held on May 17, 1961.

In recent experiments at Central Rice Research Institute, Cuttack, India, it has been found that blue-green algae was very effective in increasing paddy yields both in pots and fields, in the presence of a nutrient mixture consisting of lime 1000 kg/ha plus superphosphate 20 kg P_2O_5/ha plus sodium molybdate 0.28 kg/ha.

Increased yields have also been obtained as a result of liming in Assam and Madras states. (India.)

Similar data have been obtained in U.S.A., and other countries. The most convincing evidence of the effect of liming has come from long-term experiments on the Morrow plots at the University of Illinois, U.S.A. The plots were laid in 1876. The yields of corn (maize) on no treatment and lime NPK fertiliser plots in 1957 were 42 and 106 bushels, respectively, per acre. The initial pH of the plots is not known since modern methods of determining soil reaction were not available. However in 1955, the untreated plots had a pH of 5.0 while the pH of plots where limestone has been applied was 6.4.

6. LIMING MATERIALS

More than 90 per cent of agricultural lime is calcium carbonate; some is calcium and magnesium carbonate, and a much smaller quantity is calcium oxide, calcium hydroxide or wood ash. To a chemist, lime is calcium oxide but to a farmer and an agronomist or soil scientist, lime usually means calcium carbonate or calcium carbonate equivalent.

The common liming materials are :

1. Calcic limestone ($CaCO_3$), which is ground limestone.
2. Dolomitic limestone [$CaMg(CO_3)_2$], from ground limestone high in magnesium.
3. Quicklime (CaO), which is burned limestone.
4. Hydrated (slaked) lime [$Ca(OH)_2$], coming from quicklime which has changed to the hydroxide form on reaction with water.
5. Coral shell lime is usually recommended as a liming agent in Ceylon due to its availability in abundance.
6. Chalk ($CaCO_3$), resulting from soft limestone.
7. Blast-furnace slag ($CaSiO_3$) and (Ca_2SiO_4), a by-product of the iron industry. Some slags contain phosphorus and a mixture of CaO and $Ca(OH)_2$. This product is called basic slag and is valued mostly for its phosphorus content.
8. Miscellaneous sources, such as wood ash, ground oyster shell, press mud and by-product lime resulting from papermills, sugar factories,

tanneries, and water-softening plants, and by-product $CaCO_3$ from fertiliser factories using the gypsum process such as at Sindri, Bihar, in India.

Gypsum ($CaSO_4$) is sometimes added to the soil to supply calcium, but has no influence on soil pH. It is not considered as a liming material.

All of the liming materials mentioned have value for supplying calcium or calcium and magnesium, raising the pH, and making aluminium, manganese, and iron less toxic. The choice of which one to buy is determined by the cost in relation to its purity, the ease of handling, and fineness which determines the speed with which the lime reacts in the soil.

7. METHODS OF APPLYING LIME

The most efficient way to use lime is to apply small amounts every year or two, but this liming programme increases the cost of application. The usual liming practice consists of a compromise between what is most effective and what is the cheapest per ton of lime applied. Lime can be applied to advantage at any stage in the cropping system, but normally it is best applied several months in advance of the crop that requires it the most.

The rate of lime application should always be determined by means of soil testing. Applying two tons per acre on a field that needs four tons is short-sighted economy, since there may be little or no return on a considera-

Fig. 9.7 On acid soils in Mysore State, India, forest tree leaves have been spread and lime is now being spread and both are being ploughed into the surface of the soil.

ble cash outlay for seed, fertiliser, and lime. Similarly, liming a field that needs no lime will give no benefit at all and may be harmful.

It is desirable that newly spread lime be well mixed with the whole plough layer. On strongly acid soils, where from three to six or more tons per acre of lime are required, it is recommended that one-half of the dose be applied before ploughing and the other half be applied and worked in after ploughing. When not more than two tons per acre are needed, the entire amount can be applied and worked in after ploughing and before seeding (See Figure 9.7).

When excessively large amounts of lime are applied to sandy soils low in humus, injury to plant growth sometimes occurs. Injury to plant growth may be due to any one or a combination of these causes :

1. Boron deficiency.
2. Iron, manganese, copper, or zinc deficiency.
3. Phosphorus availability may be reduced to a critically low level.
4. Potassium uptake may be reduced.

Overliming injury may be reduced by application of large amounts of manure, green-manure crops, compost, phosphorus fertiliser, boron, or a mixture of minor elements.

In Taiwan it has been found that liming the soil when its pH is already above 6.5 was detrimental to the rice crop.

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CHAPTER TEN

SALINE AND ALKALI SOILS

He should be acquainted with the manner of sowing seeds and with the good and bad qualities of the soil."
MANU SMRITI, CIRCA THE TIME OF CHRIST.

Saline and alkali soils occur most commonly, but not exclusively, under arid climates. This is due either to the presence of an excess of sodium salts or to the predominance of sodium among the exchangeable bases. In some cases, potassium salts may be present in appreciable amounts but it is of unusual occurrence. Saline soils also occur in areas contaminated by the salt in sea water.

Saline and alkali soils have been classified as follows:

Saline soils: Saline soils were originally called "white alkali" soils. Russians term them as *solonchak* soils. Now the term is gradually changing to saline soils.

Soils are classified as saline if the solution extracted from a saturated soil paste has an electrical conductivity value of 4 or more mmhos/cm at 25^{0} C. This information is obtained on a special salt bridge, patterned after a common Wheatstone bridge. The amount of exchangeable sodium in saline soils is low, being less than 15 per cent; as a consequence, the pH is below 8.5.

Saline soils usually have a surface crust of white salts, especially in the day season when the net movement of soil moisture is upward. Salts dissolved in the soil water move to the surface, where they are left as a crust when

the water evaporates. These white salts are mostly chlorides, sulphates, and carbonates of calcium, magnesium, and sodium. Saline soils are in a flocculated condition, and consequently the excess salts can readily be leached below the root zone with irrigation water.

Alkali soils : These soils have often been called " black alkali" soils, because they are black, owing to the effect of the high sodium content which causes the dispersion of the organic matter.

The percentage of exchangeable sodium saturation in alkali soils is greater than 15; as a result, the pH is between 8.5 and 10.0. The saline content is below 4 mmhos/cm at 25°C, as measured on a salt bridge. Locally, many of the areas are known as "slick spots," because, when the soil is ploughed slightly wet, it turns over in slick, rubbery furrow slices.

Because of the high sodium content, both the clay and the organic matter are dispersed, and the result is a close packing of the soil particles. The close packing of the particles reduces the size and the amount of pore spaces, and as a consequence water and air will not move through the soil readily. Poor aeration and high sodium content, which is often toxic, make alkali soils difficult and expensive to reclaim.

Saline-Alkali soils : The term "saline-alkali" applies to soils which are both saline and alkali. There can be all stages in transition with varying degree of dominance of salt content or high pH. Usually these soils have the following characteristics :.

1. A conductivity of the saturated extract greater than 4 mmhos/cm. at 25°C.
2. Exchangeable sodium in excess of 15 per cent.
3. A variable pH, usually above 8.5 depending upon the relative amounts of exchangeable sodium and soluble salts. When soluble salts are leached downward, the pH will rise above 8.5, but when the soluble salts again accumulate, the pH may again fall to 8.5.

I. FORMATION OF SALINE AND ALKALI SOILS

In the arid regions, where there is low rainfall and high temperature, there is always a tendency for the accumulation of soluble salts near the surface. During rainy season these salts may move downward to the lower soil layers but after the rainy season, the intense evaporation brings the salts back to the surface.

The ground waters of arid regions usually contain considerable quantities of soluble salts. If the water ~~table is high, large~~ amounts of water move to the surface by capillary action and are evaporated, leaving an ever-increasing accumulation of soluble salts. This process of accumulation of soluble salts makes the soil highly impregnated with salts and only salt-resistant crops can grow.

The salts may have originated directly from chemical weathering of rocks and have been dissolved by surface and percolating waters. The salts may represent the remains of former seas or salt lakes. The usual mode of origin is from saline ground waters, either in the vicinity of inland seas or salt lakes or in depressions where the water table is at or near the surface.

The favourable conditions for formation of saline soils are : (1) a high water table with a fairly high salt concentration, (2) a high temperature, and (3) a low rainfall. Consequently, the soils of dry regions tend to become increasingly saline as long as the ground water remains within capillary reach of the evaporation from the surface of the soil.

Under irrigation, saline and alkali soils have developed by any one or more of several means, as follows :

1. When excessive applications of water have raised the ground water level sufficiently to permit concentration of salts from saline ground water through evaporation.

2. When seepage from leaky canals and lateral channels which run at a higher level has resulted in a high water table and saline/alkali soils.

3. When the irrigation water has a high salt content.

4. When poor drainage keeps the salts in the surface soil and prevents the leaching of salts, and

5. When the use of irrigation water is erratic, i.e., flooding at one time followed by intense drought. When the total supply of water is limited, this would also leave the salts in the root zone.

Saline soils may be of two kinds : (1) soils in which soluble salts contain a substantial quantity of calcium and magnesium. In these the colloids are not damaged by sodium. Usually such soils have a fair reserve of calcium carbonate, or (2) soils in which soluble salts are chiefly sodium. There is little or no reserve calcium carbonate in the soil. In these soils the sodium damages the colloidal complex and tends to increase the exchangeable sodium.

Under irrigation, soil with little or no calcium carbonate. would ultimately become an alkali soil, since the soil solution which is rich in sodium salts would increase the exchangeable sodium. The exchangeable sodium would always provide enough NaOHin soil solution to increase soil pH above 8.5.

Thus there are three distinct stages in the evolution of alkali soils. They are as follows :

(a) Salinisation.

(b) Saline-alkali soil.

(c) Alkalinisation of the exchange complex (i.e., de-salinisation and intense alkali soil formation.)

2. UNFAVOURABLE EFFECTS OF SALINE AND ALKALI SOILS

Saline soils are usually barren but potentially productive soils. These soils do not support plant growth primarily because of excessive salts in the soil solution which, due to high osmotic pressure prevents absorption of moisture and nutrients in adequate amounts. This is illustrated in Figure 10.1. Thus in saline soils the wilting coefficient is high and the amount of available moisture is low. An excess of sodium ions also exert antagonistic effects on the absorption of calcium and magnesium.

Under alkali soil conditions, the damage is not due to salt concentration, since the conductivity of the soil solution is low. The sodium adsorbed by clay and organic colloids causes dispersion of clay which results in a loss of desirable structure and the development of a puddled effect. Such effects on physical properties reduces drainage, aeration and microbial activity. The high pH in alkali soils causes a reduction in the solubility and availability to plants of iron, copper, manganese, and zinc.

Under saline-alkali conditions there may be actually several transitional stages, from high salinity-low alkalinity to low salinity-high alkalinity. Under such conditions, the crops may suffer due to high salinity as well as to unfavourable effects of alkalinity.

3. EXTENT OF THE PROBLEM

India has ten to twelve million acres of land producing practically nothing of value because of the influence of soluble salts or high alkalinity. Such lands are found in the valley troughs of the great river systems. Irrigation

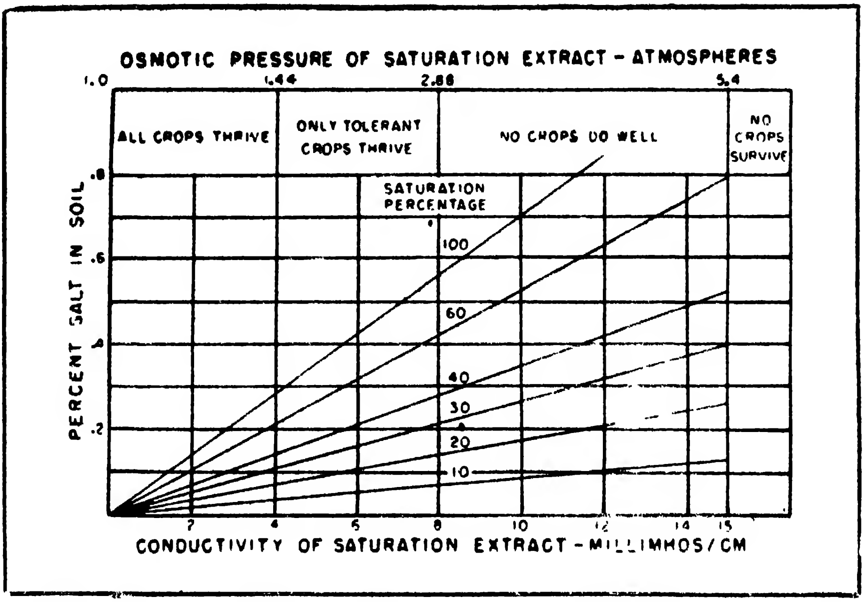


Fig. 10.1 Graphical representation of the relation of crop growth to the conductivity and osmotic pressure of the saturation extract to the per cent salt in saline soil. (*Redrawn from "Diagnosis and Improvement of Saline and Alkali Soils."* U.S. Department of Agriculture. Regional salinity laboratory. Riverside, California, 1947.)

is thus a mixed blessing; it brings in its wake the problem of waterlogging, salinity and alkalinity. The problem occurs particularly in the Indian states of Punjab, Uttar Pradesh, Madhya Pradesh, Rajasthan and Maharashtra.

Besides the barren or almost barren lands, there is also the problem of the decline in productivity. On many millions of acres there may be a decline in yields even though visual symptoms of salt injury may not be seen.

Pakistan : The problem of saline and alkali soils is prominent in West Pakistan. Saline soils are very common in Sind. A survey of soils in Sind showed that nearly 30 per cent was too saline to grow a crop without special treatment. A salt content of 1 to 2 per cent is very common but some spots may contain as much as 7 to 10 per cent of soluble salts. The chief characteristic of saline soils in Sind is that salts contain appreciable amounts of calcium and magnesium besides NaCl and Na_2SO_4. The soil is also rich in calcium carbonate and the drainage is generally good.

Other Parts of the World : Saline and alkali soil problem has been existent in several countries such as Egypt, Sudan, U. S. S. R., North China, Holland and in many Western States of the U.S.A.

4. RECLAMATION OF SALINE AND ALKALI SOILS

Before starting the reclamation of saline or alkali soils, a knowledge of the following is essential :

(a) Quality of the soil ;

(b) Quality of the irrigation water ;

(c) Nature and distribution of salts in the soil root zone ;

(d) Level of subsoil water ;

(e) Drainage conditions.

The most important point in judging the quality of soils from the reclamation point of view is whether the soil is saline or alkaline; if alkaline the degree of alkalinisation. The higher the degree of alkalinisation, the greater will be the difficulty in reclaiming it.

To obtain an adequate soil sample for chemical testing is more difficult with saline soils than with nonsaline soils. The reason is because of the uneven concentration of salts from wet season to dry season ; the amount, quality and timing of irrigation water used ; and variation from soil type to soil type. Field management history is also a very important factor to be recorded. The soil sample should be obtained from the root zone of the crops.

In judging the quality of irrigation water, it is important to take into consideration not only the total soluble salt content but also the relative proportion of calcium to sodium. If the ratio of calcium to sodium is high, it would help in the replacement of Na with calcium ions in the exchange complex.

Irrigation water analyses should include the determination of the boron concentration which sometimes occurs in toxic quantities. The bicarbonate concentration in relation to the concentration of calcium plus magnesium should also be determined for the same reason.

In at least one State in India, before a farmer can obtain a loan for making a tube well or dug well, permission must first be obtained from the Department of Agriculture. From records of soil and water analyses, the Department has information on the suitability for irrigation of the soil and the water in the general area.

Schoonover (1959) in his study of soil problems in India, has listed the following technical requirements for reclamation of saline and alkali soils :

(1) Adequate drainage.

(2) Availability of sufficient water to meet crop use and also leach the salt below the root zone in the soil.

(3) Better than average soil management to include perfect land levelling, good bunding for irrigation, and advanced agronomic practices.

(4) Protection and reclamation to be undertaken in large blocks. The establishment of drainage and the development of adequate water supplies will usually require extensive public works, developed for the benefit of large areas.

(5) Good quality of irrigation water. It is imperative that the quality of India's irrigation water supplies be studied systematically.

5. SALINE SOIL RECLAMATION

Saline soils in which the soluble salts contain appreciable amounts of calcium and magnesium do not develop into alkali soils by the action of leaching water. The reclamation is comparatively easy in such soils. The main problem is to leach the salts downward below the root zone and out of contact with subsequent irrigation water. It is, however, important that the drainage of the soil be good. Saline soils of Sind (Pakistan) have been reclaimed by the use of a heavy application of irrigation water, usually a 60 cm. dose. Less than a 60 cm. application ~~of water was not~~ effective, and higher doses did not further reduce the salt content. The original salt content of the soil was 1 to 5 per cent, but as long as a minimum dose of 60 cm. of water was used for the flooding, the soil was left at the end of leaching with a total salt content of about 0.5-1 per cent. The residual salts were chiefly salts of calcium which came from the irrigation water, while the original salts in the soil were mainly of sodium These soils after flooding supported plant growth even though the salt content of the soil was high. This was due to predominance of calcium salts.

It is important that saline areas are isolated according to textural class (i.e. more correctly drainage ability). If a plot of land, mostly sandy loam in texture but having some spots of clay soil, is taken for reclamation by flooding, the result after flooding would be that the sandy loam soil would be reclaimed and would support plant growth, while the clay soil would not. This is because more water passed downward through the sandy loam and leached more salts below the root zone. Thus, it becomes imperative that bunds are raised around plots with different textures or drainage abilities so that adequate amounts of irrigation water can be applied to each kind of soil to achieve the desired leaching.

Saline soils which do not contain sufficient soluble calcium salts or reserve calcium carbonate would be converted to alkaline soils upon leaching with water. Thus, instead of reclaiming, we would increase difficulties. In such cases the addition of calcium salts, preferably gypsum or limestone is beneficial. In the presence of calcium sulphate, the quantity of calcium is increased in soil solution, with the result that calcium displaces sodium from the exchange complex and a favourable physical change in the soil takes place.

Frequently the saline soils have a high water table, a dense gypsum layer, or are fine textured. These conditions reduce the movement of irrigation water downward and, therefore, make it difficult to leach the salts to the desired depth below the plant root zone.

In salty soils with a high water-table, artificial drainage is necessary before the excess salts can be removed. Deep chiseling or deep plowing is sometimes used on soils with impervious layers in order to open the soil for the desired downward movement of water and salt.

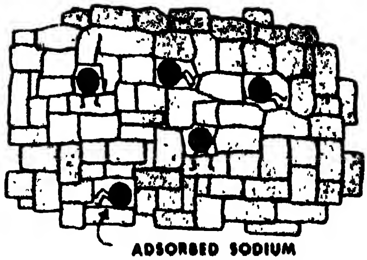
6. ALKALI SOIL RECLAMATION

In alkali soils, the exchangeable sodium is so great as to make the soil almost impervious to water. But even if water could move downward freely in alkali soils, the water alone would not leach out the excess exchangeable sodium. The sodium must be replaced by another cation and then leached downward and out of reach of plant roots.

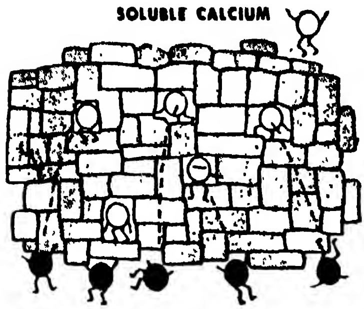
By cationic exchange, calcium is often used to replace sodium in alkali soils (Figure 10.2). Of all calcium compounds, calcium sulphate (gypsum) is considered the best for this purpose.

Applications of 18 tons of gypsum per acre in Nevada, U.S.A. increased water infiltration and increased the depth of water penetration. Three years after applying the gypsum, the same amount of water penetrated to a depth of 19 inches in the soil receiving the gypsum, and to only 10 inches in the soil which received no gypsum (Figure 10.3). This resulted in a reduction of exchangeable sodium percentage from 42 to 18 per cent during the three-year period. At the same time, the no-gypsum plot gained in exchangeable sodium from 50 to 53 per cent (Figure 10.4). Yields of hay were increased from 0.05 tons to 1.02 tons per acre per year as a result of the application of gypsum. (Figure 10.5.)

1 Too much sodium attached to clay particles tends to make the particles pack together in such a way that water cannot get through



2 Sulfur materials furnish soluble calcium, which replaces the excess adsorbed sodium.



3 This replacement allows the soil particles to group themselves so that larger pore spaces are formed

Then when the soil is flooded, the water can pass through and wash out excess salts, including sodium.

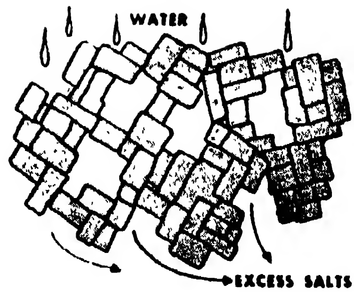


Fig. 10.2 How soluble calcium reclaims alkali soils (*Source* : Daniel G. Aldrich, Jr. and Schoonover, W. R., "*Gypsum and Other Sulphur Materials for Soil Conditioning*," California Agricultural Experiment Station. Circular 403, 1951.)

The reactions involved are :

$$2\ \text{Na Clay} + CaSO_4 = Na_2SO_4 + \text{Ca Clay}$$
$$Na_2CO_3 + CaSO_4 = CaCO_3 + Na_2SO_4$$

Gypsum converts Na-soil into Ca- soil with a desirable lowering of pH and an improvement in soil physical conditions. This also improves drainage.

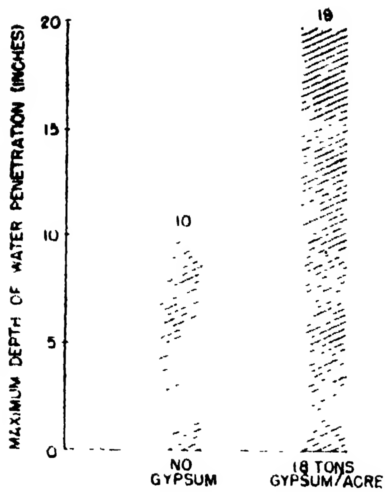


Fig. 10.3 Gypsum increases the infiltration of water in soils Maximum depth of water penetration from six irrigations (Clyde E, Houston, et al., "*Gypsum for Improving Alkali Soils*" Nevada Agr Exp Sta. Cir. 7. 1955)

Flooding is then given to remove the sodium sulphate formed from the reaction with gypsum.

In extreme cases of high alkalinity the reduction in pH is brought about by the use of sulphuric acid. The reclamation process would, however, require expert handling and would usually be quite expensive.

Sulphur is also used in reducing the alkalinity. Sulphur is spread on the soil and is oxidized to sulphuric acid, which converts sodium carbonate into sodium sulphate ; and calcium carbonate, already present or artificially added, to form Ca $(HCO_3)_2$. Calcium replaces sodium. Sodium sulphate is removed by leaching. The addition of organic matter helps in lowering the pH, improving the soil structure, and in increasing the capacity of the

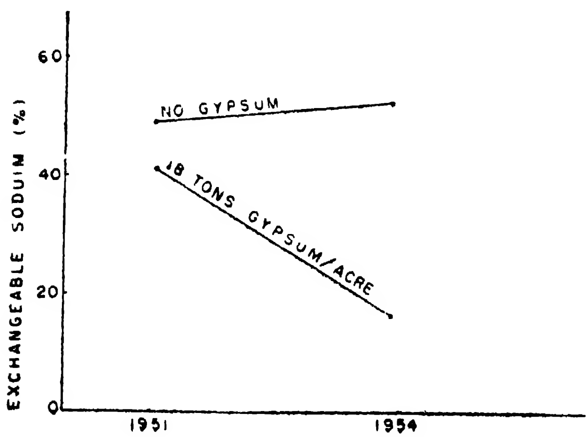


Fig. 10.4 Gypsum reduces the percentage of exchangeable sodium in soils. (Soil was sampled to a 30-inch depth.) (Clyde E. Houston, et. al., "*Gypsum for Improving Alkali Soils*," Nevada Agr. Exp. Sta. Cir. 7, 1955.)

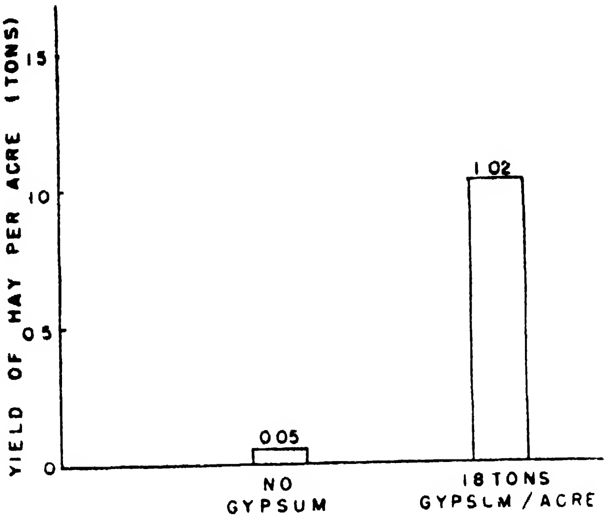


Fig. 10.5 Gypsum increased the yield of hay (dry fodder). (One application three years previously.) (Clyde E. Houston, et. al., "*Gypsum for Improving Alkali Soils*," Nevada Agr. Exp. Sta. Cir. 7, 1955.)

soil to provide available nitrogen to the crops. Organic matter is especially helpful where sulphur is added to correct the alkalinity. The organic matter supplies food for the bacteria that stimulate the oxidation of sulphur to the sulphate form. The combination of sulphur, organic manure and gypsum has also been used with success.

The amounts of gypsum and sulphur required to replace different amounts of exchangeable sodium are given in Table 10.2. It can be seen that a large quantity of gypsum or sulphur is required to reclaim alkali soils. For example, to remove 5 m.e. of exchangeable sodium per 100 gm. of soil, would require 8.6 tons of gypsum, or 1.6 tons of sulphur per acre-foot of soil. On an average for every one milliequivalent of sodium to be replaced, 1.7 tons of gypsum or 0.32 tons of sulphur is required.

Kanwar and his co-workers in India have provided evidence for the relationship of exchangeable sodium+potassium with gypsum requirement of soils in Karnal district in Punjab. This relationship is shown in Figure 10.6. These findings give almost the same gypsum requirements as those from the United States Salinity Laboratory, shown in Table 10.1.

TABLE 10.1

AMOUNTS OF GYPSUM AND SULPHUR REQUIRED TO REPLACE INDICATED AMOUNTS OF EXCHANGEABLE SODIUM FOR SOIL RECLAMATION

Exchangeable Sodium m.e. per 100 gm. of soil	Gypsum Tons/acre-ft. (4,000,000 lbs. of soil)	Sulphur Tons/acre-ft. (4,000,000 lbs. of soil)
1	1.7	0.32
2	3.4	0.64
3	5.2	0.96
4	6.9	1.28
5	8.6	1.60
6	10.3	1.92
7	12.0	2.24
8	13.7	2.56
9	15.5	2.88
10	17.2	3.20

Source · Richards, L.A., Editor. *Diagnosis and Improvement of Saline and Alkali Soils*. Agri. Handbook No. 60. United States Department of Agriculture, 1954. Page 49.

Chawla made a series of pot culture studies with wheat on a saline-alkali soil in which varying percentages of the gypsum requirement were added. The results are shown in Figure 10.7.

Dhar in India has successfully reclaimed alkali soils with the use of molasses. He recommends the use of 2 tons of molasses per acre along with 1-2 tons of press mud (a waste product in the sugar industry) and 50-100 lbs. P_2O_5 per acre in the form of basic slag. The molasses provides the source of energy for microorganism which on fermentation produce organic acids. The organic acids reduce alkalinity and increase the availability of phosphate. The addition of press mud, which contains calcium, produces soluble calcium salts that help in reducing exchangeable sodium. Under conditions of a good supply of available phosphate, nitrogen fixation is also benefited.

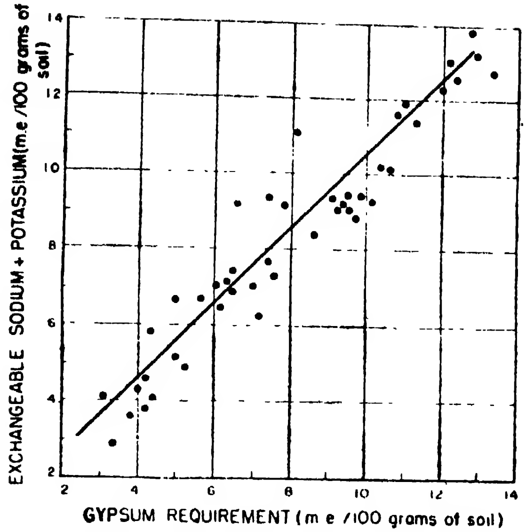


Fig. 10.6 The Relationship Between exchangeable Sadium* Potassium in Saline—Sodic Soils and Their Gypsum Requirements. *(Source: Kanwar, J.S., I L. Sehgal, and D.R. Bhumla, Journ. Indian Society of Soil Science, Vol II, 1963 p 39-44)*

Fig. 10.7 Wheat on a saline-alkali soil with a pH of 10.3, an electrical conductivity of 2.0 mmhos/cm. and an exchangeable Na+K percentage of 10.4 m.e.. responded to variable gypsum applications as shown: *

T_0 = No gypsum
T_1 – 10 per cent of gypsum requirement
T_2 = 15 per cent of gypsum requirement
T_3 30 per cent of gypsum requirement
T_4 = 50 per cent of gypsum requirement
T_5 = 70 per cent of gypsum requirement
T_6 = 100 per cent of gypsum requirement

***Note**: The gypsum requirement as determined by the Schoonover Method was 9.07 tons of gypsum per acre.

Source: Chawla, V. K., *Study of the Effect of Gypsum and Pressmud on the Physico-Chemical Properties of Saline-Alkali Soils of the Punjab.* (Unpublished M. Sc. Thesis, Punjab University, 1960.)

7. SOLODI OR DEGRADED ALKALI SOILS

The hydrolysis of sodium soil (alkali soil) with the production of sodium hydroxide involves the formation of hydrogen soil :

$$\text{Na Clay} + H_2O \rightleftharpoons \text{Na OH} + \text{H-clay}.$$

In the absence of calcium carbonate, the degradation of hydrogen soil into silicic acid and sesquioxide occurs. This situation arises in soils with excess rainfall. The process is similar to podzolization where sesquioxides are leached to lower layers. Such degraded soils are called solodi by Russian workers and the process is termed *solodization.*

Such soils are reclaimed by the use of lime, supported by adequate use of fertilisers to make up the deficiencies of plant nutrients.

8. SALT TOLERANCE OF CROPS

Under some circumstances, it may not be feasible to reduce the salt content of soils to permit the growth of sensitive crops. The alternative is to select crops which are tolerant of salt.

A classification of plants according to their salt tolerance has been made by the staff of the United States Salinity Laboratory at Riverside, California. Table 10.2 shows this list of plants in three degrees of tolerance and by four types of crops, namely, field crops, forage crops, fruits, and vegetables. In each group, the most tolerant crop is at the top of the list and the most sensitive crop is shown at the bottom.

Whereas this classification of salt tolerance of crops was established in the United States, it should be reasonably correct for Tropical Asia. However, the salt tolerance of tropical crops that are not included here should be established by research.

Of the field crops, barley for grain, sugar beet, and cotton are the most tolerant to salt, while field beans are the most sensitive. Other crops, mainly the small grains, are intermediate in salt tolerance. Sweet clovers and alfalfa (lucerne) are intermediate in tolerance.

Date palm is the only fruit known to be very tolerant of salty soils. Five fruits are shown in the table to be intermediate in tolerance; namely, pomegranate, fig, olive, grape, and cantaloupe. Most fruits are sensitive to salt concentrations in the soil.

Garden beet, kale, asparagus, and spinach are listed as very salt tolerant, while radish, celery, and green beans are sensitive. Most vegetables are intermediate in tolerance.

TABLE 10.2

RELATIVE TOLERANCE OF CROPS TO SALT*

HIGH SALT TOLERANCE	MEDIUM SALT TOLERANCE	LOW SALT TOLERANCE
	Field crops	
Barley (grain)	Wheat (grain)	Bean (field)
Sugar beet	Rice	
Cotton	Sorghum (grain)	
	Maize	
	Flax	
	Sunflower	
	Castor bean	
	Forage crops	
Alkali sacaton	Sweetclover, white	White clover
	Alfalfa (lucerne)	
	Fruits	
Date palm	Pomegranate	Pear
	Fig	Apple
	Olive	Orange
	Grape	Grapefruit
	Cantaloupe	Plum
		Apricot
		Strawberry
		Lemon
		Avocado
	Vegetables	
Beet, garden	Tomato	Radish
Kale	Broccoli	Celery
Asparagus	Cabbage	Green Beans
Spinach	Cauliflower	
	Lettuce	
	Sweet corn	
	Carrot	
	Onion	
	Peas	
	Squash	
	Cucumber	

Note : In each group, the plants named first are more tolerant and the plants named last are more sensitive to salt.

**Source :* Richards, L. A., Editor, *Diagnosis and Improvement of Saline and Alkali Soils*, Agri. Handbook No. 60, United States Department of Agriculture, 1954.

NO EFFECT ON CROPS	SENSITIVE CROPS RESTRICTED	MANY CROPS RESTRICTED	MOST CROPS RESTRICTED	FEW CROPS TOLERANT

16 32

SCALE OF CONDUCTIVITY IN mmhos/cm at 25°C

Fig. 10.8 The relationship between the salt content of soils and general crop response Source *"Diagnosis and Improvement of Saline and Alkali Soils,"* U. S. Salinity Laboratory Staff, Agri. Handbook No. 60. U.S Dept. of Agr., 1954.)

The general salt tolerance of plants in shown in Figure 10.8 in relation to the scale of electrical conductivity. The conductivity of the soil saturation extract is measured in thousandths of reciprocal ohms at a standard temperature (25°C). According to this figure, salt concentrations represented by readings of 0-2 have no influence on crop growth, 2-4 restrict the growth of sensitive crops, 4-8 limit many crops, 8-16 restrict most crops, and salt concentrations represented by readings of 16-32 prevent the satisfactory growth of all but the most salt-tolerant of crops.

Agarwal and Yadav (1956) have given a salinity and alkalinity scale to evaluate crop response rating of Indian saline-alkali soils. This is based on work done on cultivator's fields in Kanpur district, Uttar Pradesh. This scale is given in Figure 10.9.

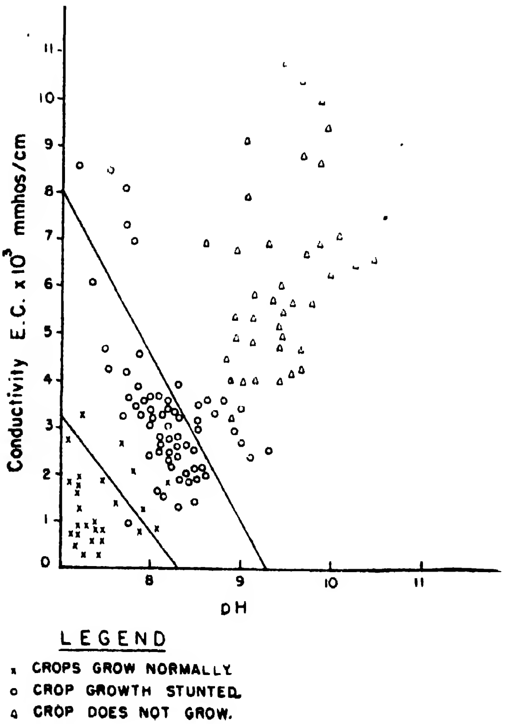


Fig. 10.9 Crop growth in India in relation to soil pH and conductivity (salt content) of the soil. (Agarwal, R R., and J.P.S. Yadav., Journal of Indian Society of Soil Science, (43), p. 141-146. 1956)

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CHAPTER ELEVEN

SOIL ORGANIC MATTER

"A field without manure is as useless as a cow without a calf."

—ANCIENT TELUGU PROVERB.

Organic matter in the soil comes from the remains of plants and animals. This includes grasses, trees, bacteria, fungi, protozoa, earthworms and animal manures. Organic matter represents a certain stage in an endless turnover of the elements, carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulphur between living organisms and the mineral kingdom. As new organic matter is formed, a part of the old becomes mineralised. Many of the desirable properties of organic matter are due to this dynamic character.

Soil organic matter may be distinguished from humus. Soil organic matter consists of any substances of organic origin, living or dead, while humus is fairly stable and amorphous, brown to black material which is formed as a result of decomposition of plant and animal residues, with no trace of the structure of the material from which it is derived. Humus in reality is not merely a decomposition product since decomposition implies transformation to simpler compounds, whereas humus is more complex than original organic matter. Besides decomposition of organic matter, synthesis of organic substances is involved in humus formation.

The principal product that is synthesized is a lignin-protein complex that some authorities designate as particles of ligno-proteinate.

I. FUNCTIONS OF ORGANIC MATTER

Organic matter serves many purposes in the soil that may be summarised as follows :

1. Coarse organic matter on the surface reduces the impact of the falling rain drop and permits clear water to seep gently into the soil. Surface runoff and erosion are thus reduced, and as a result there is more available water for plant growth.

2. The addition of easily decomposable organic residues causes the synthesis of complex organic substances that bind soil particles into structrual units called aggregates. These aggregates help to maintain a loose, open, granular condition. Water is then able to enter and percolate more readily downward through the soil. The granular condition of soil maintains favourable condition of aeration and permeability.

3. The roots of plants need a continuous supply of oxygen in order to respire and grow. Large pores make it easy for the soil to absorb oxygen from the atmosphere and to expel carbon dioxide. Live roots decay and provide channels down through which new plant roots grow more luxuriantly. The same root channels are effective in transmitting water downward, a part of which is stored for future use by plants.

4. Water holding capacity is increased by organic matter. The fact that organic matter increases the water holding capacity of the soil does not necessarily mean an increase in available water supplies to plant, since organic matter holds water fairly tightly, thus the permanent wilting percentage is increased. Organic matter definitely increases the amount of available water in sandy and loamy soils. Further, the granular soil resulting from organic matter additions, supplies more water than sticky and impervious soil.

5. Organic matter serves as a reservoir of chemical elements that are essential for plant growth. Most of the soil nitrogen occurs in organic combination. Only a small fraction, usually 1-3 per cent, occurs in inorganic forms at any one time. Also a considerable quantity of phosphorus and sulphur exist in organic forms. Upon decomposition, organic matter supplies the nutrients needed by growing plants, as well as many hormones and antibiotics. These are released in harmony with the needs of the plants. When

environmental conditions are favourable for rapid plant growth, the same conditions favour a rapid release of nutrients from the organic matter.

6. Organic matter upon decomposition produces organic acids and carbon dioxide which help to dissolve minerals such as potassium, and to make them more available to the growing plants.
7. Organic matter helps to buffer soils against rapid chemical changes in pH due to the addition of lime and fertilisers.
8. Humus provides a storehouse for the exchangeable and available cations—potassium, calcium, and magnesium. Ammonium fertilisers are also prevented from leaching because humus holds ammonium in an exchangeable and available form.
9. The organic matter serves as a source of energy for the growth of soil microorganisms. All heterotrophic organisms, e.g., nitrogen-fixing organisms, require easily decomposable organic matter as their source of carbon. Without carbon, nitrogen fixation by *Azotobacter* and *Clostridium* would be impossible.
10. Fresh organic matter supplies food for such soil life as earthworms, ants, and rodents. These animals burrow in the soil and construct extensive channels through the soil that serve not only to loosen the soil but also to improve drainage and aeration. Further this permits plant roots to obtain oxygen and to release carbon dioxide as they grow. Earthworms can flourish only in soils that are well provided with organic matter.
11. Evaporation losses of water are reduced by organic mulches.
12. Trashy, coarse organic matter on the surface of soils reduces losses of soil by wind erosion.
13. Surface mulches lower soil temperatures in the summer and keep the soil warmer in winter.
14. Fresh organic matter has a special function in making soil phosphorus more readily available in acid soils. Upon decomposition, organic matter releases citrates, oxalates, tartrates, and lactates which combine with iron and aluminium more readily than does phosphorus. The result is the formation of less of the insoluble iron and aluminium phosphates and the availabitity of more phosphorus for plant growth.
15. Organic acids released from decomposing organic matter help to reduce alkalinity in soils.

2. COMPOSITION OF SOIL ORGANIC MATTER

The composition of soil organic matter and in particular of the soil humus has been a difficult problem for soil chemists. One of the chief difficulties in investigating the problem is the impossibility of isolating the organic matter from the mineral portion of the soil.

Soil organic matter is a very complex substance. It contains the following materials, but in varying percentages, depending upon the kind of plant or animal residues and its state of decomposition.

1. Carbohydrates, including sugars, starches and cellulose.
2. Lignin
3. Tannin
4. Fats, oils, and waxes
5. Resins
6. Proteins
7. Pigments
8. Minerals such as calcium, phosphorus, sulphur, iron, magnesium, and potassium.

Waksman and Stevens have proposed a scheme by which recognisable groups of plant constituents are estimated :

ORGANIC MATTER

Extract with ether

- *Soluble* — Fats, Oils and Waxes 0.5-4.7%
- *Insoluble* — Treat with alcohol
  - *Soluble* — Resins 0.5-3%
  - *Insoluble* — Treat with hot 2% HCl
    - *Soluble* — Hemicelluloses, 5-12% Pentosans & hexosans
    - *Insoluble* — Digest with cold 80% sulphuric acid
      - Cellulose 3-5%
      - Lignin 35-50%
      - Protein 30-55%

By far the largest percentage of soil organic matter is lignin and protein, although humus may contain as much as 30 per cent polyuronides. In representative soils over the nation, lignin and protein percentages will each vary from approximately 25-50 per cent. The typical composition values of lignin and protein for soil organic matter in a Podzol a Chernozem, a Chestnut, and a Sierozem soil are given in Table 11.1. The Podzol is highest in lignin while the Chernozem is the lowest in lignin percentage. The Sierozem soil organic matter contains the most protein, and the Podzol the least protein.

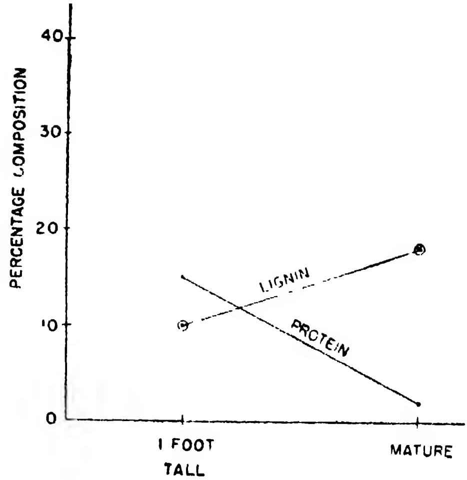

Fig. 11.1 The change in the lignin and protein percentage of a rye plant with maturity (*Soil Science*. 24 : 317, 1927.

Fresh plant material varies in percentage of lignin and protein from one species to another. Alfalfa, for example, contains more protein and less lignin than a rye plant. However, in common with all plants approaching maturity, the percentage of lignin increases and the percentage of protein decreases. This relationship is shown in Figure 11.1 for rye.

When the rye plant was 1 foot high, the lignin was 10 per cent ; at maturity the percentage had increased to 17. Protein decreased from 15 per cent to 1.5 per cent during the same two stages of growth.

TABLE 11.1

LIGNIN AND PROTEIN IN REPRESENTATIVE SURFACE SOILS*

Soil and Location	Lignin Per cent	Protein Per cent
Podzol Soil from Michigan, U.S.A. (A_2 horizon)	46	28
Chestnut Soil from New Mexico, U.S.A. (0—15 cm)	40	33
Sierozem Soil from Arizona, U.S.A. (0—15 cm)	35	50
Chernozem Soil from Oklahoma, U.S.A. (0—20 cm.)	33	38

**Soil Science*, 40 : 347—363, 1935.

A different approach in the study of organic matter composition has been made by several workers by fractionating soil organic matter and studying the properties of each fraction. A possible fractionation of soil organic matter is shown in the following scheme.

SOIL ORGANIC MATTER

Strongly coloured humic matter — Non humic matter (undecomposed plant remains)

Treat with alkali

Insoluble in cold alkali (Humin) — *Soluble* in cold alkali

Treat with acid, adjust pH to 1-2. *Soluble* in cold alkali

Insoluble in dilute acids (humic acid or humus) — *Soluble* in dilute acids (Fulvic acid)

Treat with alcohol — Add NaOH and bring to pH 4.8

Insoluble in alcohol (humic acid) — *Soluble* in alcohol (hymatomelonic acid) — *Soluble* (fulvic acid) — *Insoluble* (B—humus)

These fractions are not pure chemical compounds but consist of a mixture of substances that are colloidal in nature.

3. ORIGIN OF HUMUS

In cultivated soils as much as nine tenth of the soil organic matter may consist of humus in intimate mixture with inorganic colloids and is called a clay-humus complex. Different theories have been advanced to explain the origin of humus. The scientists and their theories are briefly given.

Geltser : Humus is not of plant origin but the product of autolysis of the bodies of bacteria which have developed on the hyphea of fungi.

Kononova : Humic substances are formed by cellulose decomposing myxobacteria before lignin has begun to decompose. Humic acids are formed at the time of intense cellulose decomposition by the interaction of organic nitrogen compounds in the myxobacterial protoplasm with soluble polyphenols (tannins, lignin, and precursors). The reaction is catalyzed by oxidative enzymes of the myxobacteria. In many respects

this work substantiates the views of Geltser Laatsch, and co-workers. Humic acid of high nitrogen occurs in soil as metabolic and autolysis products of microorganisms. Humic acid is formed by a mechanism involving condensation or polymerisation of a quinold metabolic product of the microorganisms under slightly alkaline conditions.

Enders : The metabolic processes of microorganisms are disturbed by autolysis. The decomposition products of proteins (amino acids) and carbohydrates (methy glyoxal) are no longer used in the normal metabolism and condense to form humic substance.

Waksman : Waksman and his coworkers have demonstrated the role of lignin in the formation of humus. Thus, humus is formed due to association of proteins on the modified lignin.

The points in favour of this theory are :

(a) The plant carbohydrates are readily decomposed by microorganisms, and lignin being more resistant to microbial decay, accumulates. Soil nitrates also do not accumulate in the soil until the ratio of lignin to protein is reduced to 20 to 1 or less. Thus there are favourable conditions provided for the association of lignin-proteins.

(b) Soil organic matter has been analysed for different constituents and has been found to be rich in lignins and proteins. (See Table 11.1). The lignin and protein account for about 80 per cent of the organic matter in the soil.

(c) Waksman and coworkers have also demonstrated the formation of a lignin-protein complex which had similar properties to soil humus.

(d) Rothamsted workers have reported that nitrogen in humus is in the protein form and the rate at which humus is formed is approximately proportional to the loss of lignin. These results support the lignin-protein mechanism of humus formation.

The drawback of this theory is :

If humic acid is hydrolysed with dilute HCl, the amino acids recovered account for 40-60 per cent of the N. The remaining nitrogen is resistant to hydrolysis, hence, all nitrogen in humus would not be in a protein combination ; some is likely to be in the amine form.

Mattson and Koulter-Anderson : Humic substances are formed by fixation of ammonia on lignin-complexes. Primarily it is considered to be an ammonia-lignin complex. Proetins may also occur. Ammonia is known to be fixed in soil by both inorganic and organic fractions. Mattson and Koulter-Anderson have found that lignin was able to fix ammonia in non-exchangeable form under field soil conditions. The fixed ammonia is quite resistant and is not easily available for plants. Fixation is favoured in the pH range of 7.7—8.0.

The role of lignin in humus formation is established but the actual mechanism and the relative importance of ammonia, or amino acids or proteins still remain to be worked out.

4. CARBON : NITROGEN RATIO

When fresh plant residues are added to the soil, they are rich in carbon and poor in nitrogen. The content of carbohydrates is high. This results in wide carbon nitrogen ratio which may be 40 to 1 or more. Upon decomposition the organic matter of soils changes to humus and have an approximate C:N ratio of 10:1.

Chernozem soils have a lower C:N ratio than Podzol soils due to higher pH of Chernozems. Slightly alkaline reaction is considered favourable for fixation of ammonia in organic compounds.

Rothamsted workers have shown that different types of manures and cropping had little effect on the C:N ratio, although the carbon and nitrogen contents were changed. Table 11.2 gives the nitrogen to carbon ratio of several common organic materials which are frequently incorporated in the soil. Fresh residues which are rich in carbon have a wide C:N ratio (40:1 or more). For example, wheat straw, when added to the soil, increases the soil microbial population, particularly that of ammonifiers and nitrogen fixers, and a large quantity of carbon dioxide would be released. In this process, all of the mineral nitrogen, ammonical, and nitrate nitrogen is immobilized by its being used for synthesis of body protein by microorganisms. When the decomposition of fresh organic residues has proceeded to the extent when the C:N ratio is reduced to 20:1 or so, available nitrogen in soil tends to increase. Figure 11.2 shows the effect of lucerne (alfalfa) with narrow C:N ratio (13:1) and oat straw with wide C:N ratio (80:1) on the availability of nitrogen. When wheat or oat straw is added to the soil, it depresses the available nitrogen from four to six

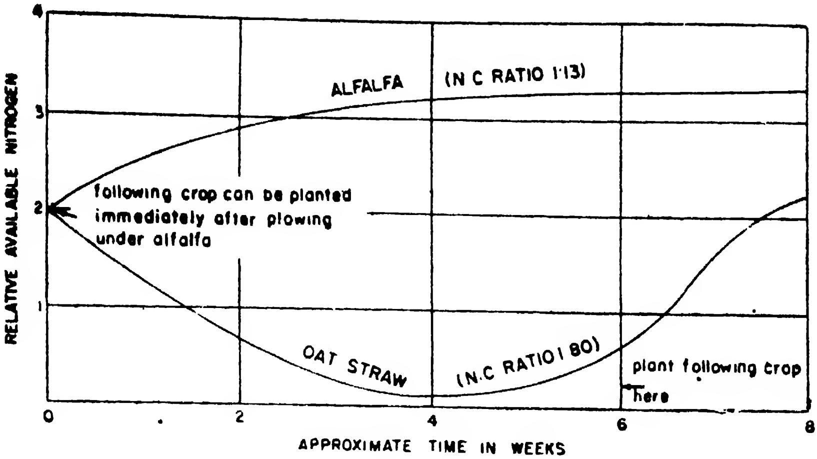

Fig. 11.2 The relationship between the N:C ratio of plant material and available nitrogen following their incorporation in the soil.

weeks. This time, of course, would vary with moisture, temperature, and general soil fertility. If the crop is planted within this period, the growth would suffer.

TABLE 11.2
THE NITROGEN, CARBON, AND N C RATIO OF COMMON ORGANIC MATERIALS

Organic Material	Total Nitrogen Per cent	Total Carbon Per cent	N C Ratio
Alfalfa (lucerne)	3.0	39	1·13
Green sweetclover	2.5	40	1:16
Mature sweetclover	1.7	39	1·23
Legume-grass hay	1.6	40	1:25
Oat straw	0.5	40	1:80

Lucerne when plowed in helps to release available nitrogen more quickly in about 2 weeks provided moisture and temperature conditions are optimum.

Low ratios of carbon to nitrogen (10 :1 or smaller) in soil organic matter generally indicate an advance stage of decomposition and resistance to further microbiological decomposition. A wide ratio of C:N (35:1 or more) indicates little decomposition, susceptibility to further and rapid decomposition and slow nitrification.

In view of the above discussion, it has always been considered profitable to mix the highly carbonaceous material like straw with a small quantity of ammonium sulphate. With this available source of nitrogen from ammonium sulphate, the decomposition of fresh organic material is hastened and thus the release of available nitrogen (ammonical and nitrate nitrogen) is affected in a shorter period of time.

5. NITROGEN AND CARBON STATUS OF INDO-GANGETIC ALLUVIUM (INDIA)

Cultivated soils : Jenny and Raychaudhury have reported the carbon : nitrogen content of 101 cultivated soils from alluvium in north west India. The mean nitrogen content is 0.044 ± 0.0019 per cent, while the corresponding organic carbon content is 0.420 ± 0.021 per cent. The figures assess the entire range in N and C regardless of climatic and soil texture effects. The mean carbon:nitrogen ratio is $9.45 + 0.63$. The C:N ratios of different soils in India are given in Table 11.3.

TABLE 11.3

CARBON : NITROGEN RATIO OF SOME INDIAN SOILS

Precipitation (annual) (cm)	Indo-Gangetic Cultivated Soils	Indo-Gangetic Virgin Soils	North Western Himalayan Forest Soils	North Western Himalayan Cultivated Soils (Simla)
25— 51	8.46	9.5		
52— 76	8.93	9.4		
79—102	9.69			
104—127	10.8	11.5		
130—152	10.3	12.1		
155				12.2
216—224			13.9	

Source : Jenny, H., and Raychaudhury, S. P., *Effect of Climate and Cultivation on Nitrogen and Organic matter Reserves in Indian Soils.* ICAR, New Delhi, 1960.

6. ORGANIC MATTER CONTENT OF PHILIPPINE SOILS

Soil organic matter was determined on 350 surface soils (0-6") at 35 locations in Luzon, Visayas, and Mindanao, Philippines, and the results are as follows :

as follows :

Range in per cent O.M.	*Percentage of soil samples in each range*
< 1.0	4.9
1.1—1.5	8.0
1.6—2.0	20.9
2.1—2.5	16.6
2.6—3.0	15.4
3.1 -3.5	8.9
3.6—4.0	6.6
> 4.0	18.9

The percentage of organic matter most frequent is approximately 2 per cent*.

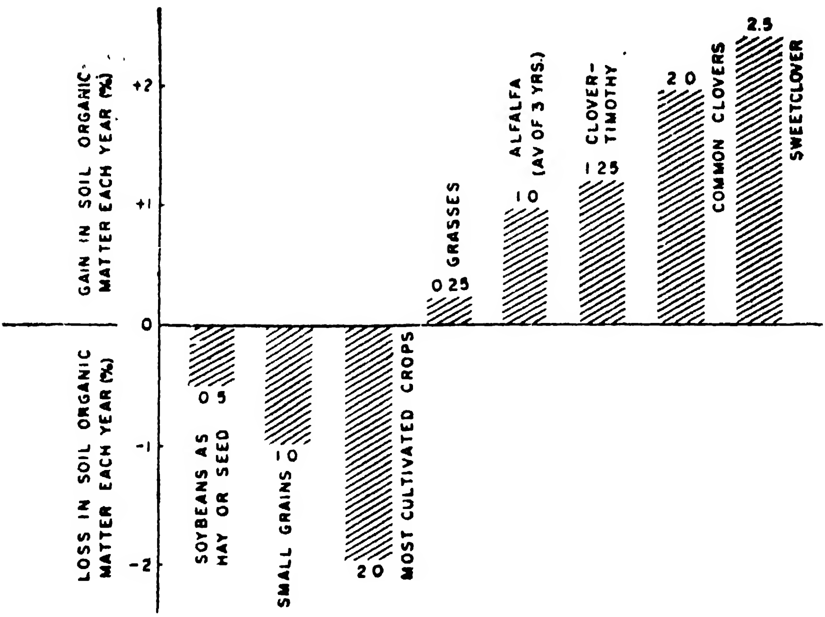

Fig. 11.3 The annual gain or loss in percentage of soil organic matter under different cropping systems in the Corn Belt. (Salter, Robert M., Lewis, R.D., and Slipher, J.A., *Our Heritage the Soil. Ohio Agr. Ext Bul. 175, 1941.)*

* *Source :* Undated Mimeographed release from the Department of Soils, College of Agriculture, College, Laguna, Philippines.

Fig. 11.4 Continuous cultivation of soils in India for centuries **(above)**, the practice of removing all crop residues for use as fuel **(centre)**, and the use of cattle manure for fuel instead of applying it to the soil, have all three contributed to a decrease in soil organic matter.

7. MAINTAINING SOIL ORGANIC MATTER IN HUMID REGIONS

Maintaining soil organic matter is difficult anywhere, and under continuous tillage it is nearly impossible. Figure 11.3 summarizes long-time studies in Ohio.

When cultivated crops are grown, the cropping system designed to maintain organic matter must include those crops which result in increases of organic matter. The Figure 11.3 shows that most cultivated crops such as corn (maize) results in a loss of soil organic matter equal to 2 per cent a year. Each year that a clover like red clover is grown, an increase of 2 per cent in organic matter may be expected. One year of a cereal crop and one year of red clover will therefore maintain soil organic matter. In a like manner, a rotation of berseem-cotton or berseem-rice in Tropical Asia should just maintain the organic matter level of the soil. This would be especially true if crop residues are left on the soil. (See Figure 11.4.)

Melsted has reported that approximately 5 tons of straw per acre or its equivalent is necessary to maintain soil organic matter under conditions of continuous tillage.

8. MAINTAINING SOIL ORGANIC MATTER IN SEMIARID AND ARID REGIONS

It is more difficult to maintain organic matter of soil under semiarid and arid climate due to the high temperatures prevailing. Losses of soil organic matter under different cropping systems of South Dakota (U. S. A.) are given in Figure 11.5.

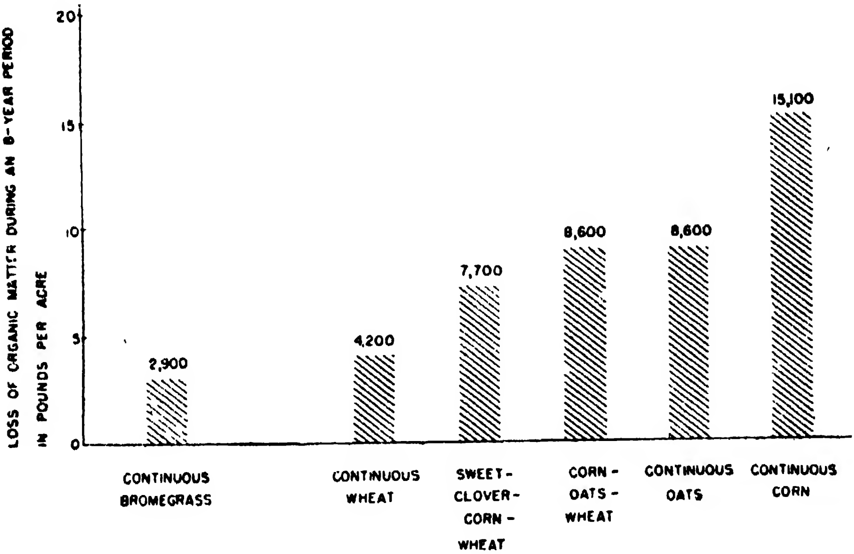

Fig. 11.5 Losses of soil organic matter during an eight-year period under different cropping systems in South Dakota (average annual precipitation, 20 inches) (Puhr, Leo F., and Worzella, W W, '*Fertility Maintenance and Management of South Dakota Soils*. South Dakota Agr. Exp Sta Cir 92, 1952.)

Continuous grass was most effective in reducing losses of soil organic matter. Next in order of desirability are continuous wheat, sweetclover-corn-wheat, corn-oats-wheat, continuous oats, and continuous corn. These losses took place during an 8-year period in South Dakota (U. S. A.).

Maintenance of soil organic matter at a satisfactory level in cultivated soils is generally recognised as one of the major problems of agriculture. The supply of organic residues is limited and most of these materials are oxidized rather rapidly. Allison, Sherman, and Pinck (1949) in their studies have reported that the quantity and nature of the inorganic soil colloid affect the rate of loss of carbon and the quantity of humus formed from readily decomposable plant materials. Montmorillonite exerted the greatest effect in holding carbon. The increase due to the addition of 10 per cent

bentonite to sand was nearly two fold in some cases. Kaolinite showed the least effect, while the soil containing a mixture of montmorillonite and hydrous mica showed an intermediate effect.

Comparison of the carbon retention values in a kaolinite soil with those in a montomorillonite soil showed no very striking differences. This may have been due in part to the higher acidity of the kaolinite soil, which would retard the decomposition. Inorganic colloids, especially montmorillonite, protect proteins and their degradation products against attack by microorganisms through the formation of organic-montmorillonite or organic-inorganic colloidal complexes.

In their further studies Pinck, Allison, and Sherman (1950) have reported that the percentage of added carbon left in the soil after an extended period of decomposition is determined primarily by the composition of the materials added and not by their carbon-nitrogen ratios. These workers have emphasized that supplemental addition of nitrogen to nitrogen-deficient crop residues did not affect the amount of carbon retained in the soil during the process of humus formation. The main effect of addition of nitrogen was only to accelerate the process of humus formation and to feed the crop if present. Where nitrogen is deficient, carbonaceous materials tend to remain in a partly decomposed condition.

Bartholomew (1948) is of a similar view and that the benefit of supplemental nitrogen to the nitrogen-deficient crop residues is beneficial for the growing crop due to increased amount of available nitrogen but that it had no effect on the amount of humus left.

Melsted is of the view that additions of inorganic nitrogen to N-deficient residues does have a beneficial effect on the amount of humus formed.

Another question that arises from the maintenance of soil organic matter level is whether the addition of readily decomposable organic matter to the soil accelerates losses of soil humus. One school of thought, Allison (1951) is of the opinion that such additions have no effect on the decomposition of native organic matter. On the other hand, Broadbent (1953) is of the opinion that addition of readily decomposable organic matter acts like adding fuel to the bacterial fire and has significant effect on the decomposition of native organic matter, presumably due to increased microbial activity.

9. LEGUME RESIDUES FOR BUILDING OR MAINTAINING ORGANIC MATTER

According to Waksman, lignin is necessary in maintaining soil organic matter, hence, materials which are rich in lignin should be added to the

soil. He is of the opinion that legumes are necessary for maintaining the organic matter level. Allison, however, is of the opinion that the quantity of organic residues is more important than the C/N ratio in the maintenance of organic matter.

Bray maintains that even different grasses with artificial N fertilisation would help to maintain organic matter levels. The supply of nitrogen helps to increase crop growth, which leaves a greater amount of root residues.

Russel from Rothamsted experiments has shown that 30 years of continuous cropping with maize depleted the soil organic matter by nearly 66 per cent and continuous wheat, by 40 per cent. The depletion of organic matter was considerably reduced by a 3 year rotation of maize—oats—clover. The loss of organic matter with this rotation was only 15 per cent.

10. DETERMINATION OF SOIL ORGANIC MATTER

Due to the importance of soil organic matter, its determination is made as a routine procedure. However, there is no accurate method available because of the complex nature of the organic matter.

Essentially there are two methods for direct determination of organic matter, "loss on ignition", and "oxidation with hydrogen peroxide". The known quantity of the soil is ignited and the loss in weight is determined. The loss in weight includes hydroscopic moisture, carbon dioxide from calcium carbonate, and carbon dioxide from elemental carbon present as charcoal. Thus the results are high and loss in weight in the above determination is usually referred to as "Loss on ignition". This method is therefore hardly useful in determining organic matter content of soils. This method is fairly satisfactory for peats and composts.

In another method, the organic matter is destroyed by hydrogen peroxide. This method can be used in soils which do not contain high MnO_2 nor more than 1 per cent $CaCO_3$. Generally low results are obtained by this method.

In view of these difficulties, a better estimate of organic matter is obtained by determining organic carbon. The organic carbon then is multiplied by a factor 1.724 to get the figures for organic matter. The carbon percentages in organic matter from different soils vary but this method gives a close approximation. The most accurate method available is the dry combustion procedure. In this method, a known quantity of soil (previously treated with sulphurous acid to destroy calcium carbonate) is ignited. The carbon dioxide evolved is weighed in soda-lime tubes. The increase in weight is CO_2 from organic matter. The amounts of organic carbon and organic matter are then calculated. This method is good but

time-consuming and only a limited number of samples can be finished in a day. Besides, this method does not exclude CO_2 from elemental carbon present as charcoal. The equipment also is relatively expensive.

A quicker and easier method is to affect the oxidation of organic matter by chromic acid. A known quantity of soil, ground to pass a 0.5 mm. sieve, is teated with a standard $K_2Cr_2O_7$ solution in the presence of concentrated sulphuric acid. The excess of $K_2Cr_2O_7$ is determined by titrating against a standard $FeSO_4$ solution. This method forms the basis of the Walkley and Black procedure for determining organic carbon. The method is quick and good for comparing related soils. It gives only 75-80 per cent oxidation. If it is intended to obtain figures for organic matter, a comparison should be made with the dry combustion procedure for every soil type. It is now usual procedure to express the values as "Walkley and Black's organic carbon values".

II. NITROGEN AND ORGANIC MATTER IN RICE PADDY SOILS

Controversy exists as to whether rice paddy soils contain more organic matter or less than non-paddy cultivated soils. Evidence on this controversy has been provided by Jenny and Raychaudhury for soils of Malabar and Kerala coasts, showing a higher content of nitrogen in paddy soils. These workers attribute the higher content of organic matter in paddy soils to an efficient soil management system in that the organic matter is renewed by incorporating animal manure, green manure, compost, town refuse, and tank silt. Also nitrogen fixation by algae may also be a significant contribution to additions of organic matter in rice paddy soils.

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CHAPTER TWELVE

BIOLOGICAL PROPERTIES OF SOIL

"All dead things—rotting corpse or stinking garbage returned to earth are transformed into wholesome things that nourish life. Such is the alchemy of mother earth."

RAMAYANA
(As interpreted by C. Rajagopalachari)

"The source of nitrogen in the soil was an early stumbling block to the balance-sheet theory of soil-plant relationships. The question was cleared up in the 1880's with the discovery that Rhizobium organisms grow in the nodules on the roots of leguminous plants and fix nitrogen from the air into forms that plants can use." (CHARLES E. KELLOGG)

The soil is not a dead mass. There is life in the soil. Soil life consists of plant roots, earthworms, microscopic protozoa and nematodes and such microscopic plants as bacteria, fungi, actinomycetes and algae. Besides, certain types of mammals (mice), arthropods (mites, millipedes, centipedes), and gastropods (snails) inhabit the soil. The total population of all soil life is numbered in billions per gram of soil, and the live weight per acre may be as much as five tons.

Because of the production of enzymes, carbon dioxide, and organic matter, the life in the soil is responsible for making numerous transformations which change plant nutrients to more readily available forms and to make and stabilise desirable soil structure for more luxuriant plant growth.

I. DISTRIBUTION OF SOIL MICROFLORA

The soil microflora consists mostly of bacteria, actinomycetes, fungi, and algae. Table 12.1 gives a recent estimate of the average number of

microflora per gram of soil and the live weight per acre to plow depth. Bacteria are estimated to average 1 billion per gram ; actinomycetes, 10 million ; fungi, 1 million ; and algae, 100 thousand, per gram of soil. The soil microflora are not of the same size. The total live weight per acre to plow depth is, therefore, not in the same order as the numbers. Fungi exceed in live weight per acre with 1,000 pounds, followed in order by actinomycetes with 750 pounds, bacteria with 500 pounds, and algae with 150 pounds. This totals 2,400 pounds of live weight of microflora per acre to plow depth. The number of microflora, however, vary widely from place to place and from season to season.

TABLE 12.1

THE AVERAGE NUMBER OF THE SOIL MICROFLORA AND THEIR LIVE WEIGHT PER ACRE TO PLOW DEPTH*

Group	Average Number Per Gram of Soil	Live Weight perc Acre to Plow Depth (Pounds)
Bacteria	1 billion	500
Actinomycetes	10 million	750
Fungi	1 million	1,000
Algae	100 thousand	150
Total		2,400

* Clark, Francis E. *A Perspective of the Soil Microflora.* Soil Microbiology Conference, Purdue University, Lafayette, Indiana, U.S.A., June, 1954.

2. HISTORICAL DEVELOPMENT OF SOIL MICROBIOLOGY

Liebig (1856) believed that nitrogenous organic matter decayed in the soil by a chemical process, with the formation of ammonia and nitrate.

Pasteur in 1862, however, believed that the transformation of ammonia to nitrate (called nitrification) takes place due to bacterial activity.

Schloesing and Muntz in 1877 demonstrated the biological nature of nitrification in soil. During their studies on purification of sewage water through a column of sand and limestone, ammonia was found to be converted to nitrate, after a lapse of 20 days. The process of conversion of ammonia to nitrate was stopped by the addition of chloroform, but the removal of chloroform reactivated the bacterial action. A similar result was obtained after heat sterilization.

The foregoing results were confirmed by Warington (1879) in England. He established that nitrogen compounds rapidly change to nitrate in the soil and that plants utilize nitrate as their food. He further showed that

conversion of ammonia to nitrate occurred in two steps. He obtained some mixed cultures but could not isolate the organism in pure cultures.

Winogradsky (1890) was the first microbiologist to have isolated the organisms responsible for converting ammonia into nitrates. He further showed that the organisms involved were autotrophs, one changing ammonia into nitrites and the other changing nitrites into nitrates.

For many years legumes had been known to enrich the soil. Hellriegel and Wilfarth (1885) found that the growth of nonleguminous crops like oats was directly proportional to the amount of nitrate added to the soil, but no such relationship was obtained in the case of leguminous plants. Further, there was no gain in nitrogen in the case of nonlegumes, while with legumes, gains in soil nitrogen occurred. They concluded that legumes fix nitrogen through the agency of bacteria existing in the nodules on their roots.

The problem of enrichment due to legumes was finally solved with the isolation of the specific organism from the nodules on legume roots by Beijerinck in 1901. The organism was called *Bacillus radicicola* but is now known as genus *Rhizobium*.

3. CLASSIFICATION OF MICROORGANISMS

The principal microorganisms include bacteria, fungi, actinomycetes, algae, and microscopic forms of protozoa. The bacteria are classified as follows :

I. Autotrophic Bacteria
  - A. Nitrifying bacteria
  - B. Sulphur bacteria
  - C. Iron bacteria
  - D. Manganese bacteria
  - E. Hydrogen bacteria
  - F. Carbon monoxide bacteria
  - G. Methane bacteria

II. Heterotrophic Bacteria.
  - A. Nitrogen-fixing bacteria.
    1. Symbiotic, *e.g.*, *Rhizobium*
    2. Nonsymbiotic
       - a. Aerobic, *e.g.*, *Azotobacter*
       - b. Anaerobic, *e.g.*, *Clostridium*
  - B. Nonnitrogen-fixing bacteria
    1. Aerobic, *e.g.*, ammonifiers
    2. Anaerobic, *e.g.*, denitrifiers

4. AUTOTROPHIC BACTERIA

The autotrophic bacteria obtain carbon from the carbon dioxide of the atmosphere and their energy from the oxidation of simple carbon compounds or from inorganic substances. These organisms are self sustaining, i.e., they can build complex compounds required for their living processes by using very simple inorganic substances. Specific groups of autotrophic bacteria are capable of oxidizing ammonia, nitrate, sulphur. iron, manganese, hydrogen, carbon monoxide, or methane.

Probably the most important groups of autotrophic bacteria are those that oxidize ammonia to nitrite and nitrite to nitrate. These groups are known as nitrifying organisms or nitrifiers.

5. HETEROTROPHIC BACTERIA

Heterotrophic bacteria comprise the majority of soil bacteria. They depend upon organic substances for their energy source and are primarily concerned with the decomposition of cellulose and other carbohydrates, proteins, fats, and waxes. Functionally, they bring about mineralisation of organic matter through hydrolysis and oxidation and release nitrogen, phosphorus, and other nutrients in forms available to plants. Nitrogen-fixing bacteria are another important class of heterotrophic organisms. These organisms can work under aerobic conditions (i.e., when oxygen or air is available) or under anaerobic conditions (i.e., when oxygen supply is absent or deficient.)

6. FUNGI

Soil fungi may be parasitic, saprophytic, or symbiotic. Parasitic fungi produce plant diseases such as cotton root rot, and many kinds of wilts, rusts, blights, and smuts. Saprophytic fungi obtain their energy from the decomposition of organic matter. Symbiotic fungi live on the roots of certain plants and both fungus and plant are mutually benefited.

Fungi are especially useful in the soil because they break down the somewhat resistant cellulose, lignin, and gum, as well as the more readily decomposed sugars, starches, and proteins. A large part of the slowly decomposing soil humus consists of the dead remains of fungal hyphae.

Mycorrhiza, meaning "fungus root", is the name given to a symbiotic association of fungal mycelium and roots of certain trees and shrubs. It is presumed that mycorrhiza aid the host plant in the absorption of certain

nutrients. Forest nurseries that have been established to raise tree seedlings that are not native to the area usually need an artificial inoculation of the suitable mycorrhiza. The reasoning behind this practice is that in a new region the compatible mycorrhiza are usually not present in the soil. There are two general types of mycorrhizae, based upon their manner of growth.

Ectotrophic mycorrhiza are usually formed by members of *Agaricales*, including mostly mushroom-type fruiting fungi. They grow as threadlike filaments into small roots *between* the root cells, but not *into* the cells. Their function appears to help the tree roots absorb nutrients by increasing their absorbing surfaces. Trees that have the ectotrophic type of mycorrhiza are the pines, spruces, oaks, elms, beech, hickories, chestnut, and birches.

Endotrophic mycorrhiza are usually formed from species of *Phoma* and *Pythium*. The fungal hyphae penetrate the plant root cells. Upon dying, mycorrhizal tissues are absorbed and utilized by the growing trees. Trees and other plants whose roots often have endotrophic mycorrhiza growing into them are sweet gum, poplars, maples, laurels, azaleas, rhododendrons, and orchids.

7. ACTINOMYCETES

Actinomycetes are taxonomically and morphologically related to both fungi and bacteria but have recently been classified as bacteria. They are characterised by branched mycelia, similar to fungi, and resemble bacteria when the mycelia break into short fragments.

In recent years, actinomycetes attracted world wide attention after it was discovered that they produced many antibiotics. At present nearly 500 antibiotics have been isolated from actinomycetes. The most common antibiotics from actinomycetes are streptomycin, aureomycin, terramycin, and neomycin.

Actinomycetes are found in fairly large quantities in all soils where the environment is satisfactory. They thrive best when there is ample fresh organic matter, when the soil is neutral to slightly acid, and when soil moisture is fairly abundant. They grow better than fungi, however, when the soil is fairly dry.

The primary function of actinomycetes is in decomposing organic matter, especially cellulose and other resistant forms.

Potato scab disease, an *Actinomyces* can be readily controlled by keeping the pH of the soil below 5.0.

8. ALGAE

Soil algae are microscopic chlorophyll-bearing organisms. The main groups are :

1. Green
2. Blue-green
3. Yellow-green
4. Diatoms

Algae develop best in most fertile soils. The green color of the soil surface following the application of commercial fertilisers is due to an increase in the number of algae.

The probable effect of algae on plant growth is to :

1. Add organic matter to the soil. The organic matter is manufactured by the chlorophyll in the algae.

2. Improve soil aeration—especially of rice paddies by excreting oxygen for use by the rice plants.

3. Fix atmospheric nitrogen. Only a few groups of the blue-green algae can do this.

Certain members of the blue-green algae have been demonstrated to fix atmospheric nitrogen. The best pH range for this fixation is between 7.0 and 8.5. In flooded rice fields, this group of algae helps to maintain the nitrogen level of the soil by utilizing atmospheric nitrogen. Also, in desert soils blue-green algae are the dominant microorganisms and may be responsible for the high nitrogen content of many surface soils.

The high fertility of Japanese rice paddy soils is attributed partly to the fixation of nitrogen by algae. The studies of De, Singh, Relwani and others have shown a significant contribution of blue-green algae to nitrogen fixation in rice paddy soils of India.

9. AMMONIFICATION

The transformation of organic nitrogenous compounds into ammonia is called ammonification. Heterotrophic organisms which form the bulk of soil population break down organic matter into simple substances available for plant nutrition or for further oxidation by autotrophic organisms.

During the course of action under aerobic conditions by heterotrophic organisms, oxygen is taken up and CO_2 is released. Like higher plants, microorganisms require a number of mineral nutrients, and a deficiency of any one of the nutrients would reduce microbial action and thus the rate of CO_2 production. Desai and Sunderarao have used this principle to obtain a correlation between CO_2 production and nutrient status of soil.

The work of several eminent microbiologists like Winogradsky and Warington have shown that the ammonification process involves a gradual simplification of complex compounds.

Proteins $\rightarrow$ polypeptides $\rightarrow$ amino acids $\rightarrow$ ammonia or ammonium salts

The ammonification occurs as a result of action of enzymes produced by microorganisms. Their action is chiefly hydrolytic and oxidative. For best results, well drained, aerated soils are best suitable for rapid ammonification.

Part of the ammonia or amino acids is utilized for building up of the body proteins of microorganisms. They use organic compounds as their nitrogen source, but when the organic matter has a very wide carbon : nitrogen ratio (i.e., there is a greater proportion of nonnitrogenous organic matter) the organisms use nitrate or ammonia if it is available in soil. Thus the significant and immediate effect after the addition of large quantities of easily oxidisable carbohydrates like molasses or straw would be immobilization of nitrate and ammonia. If no nitrogen is added with sugars, the organisms would draw upon the soil nitrogen which will be built into the bodies of the microbes. This nitrogen is not lost to the soil but it is gradually released after the dead bodies of organisms decay. A crop should never be grown immediately after the addition of large quantities of carbonaceous residues, otherwise the crop would suffer due to lack of available nitrogen. Another disadvantage to crops is the heat produced as a result of decomposition of a large amount of organic matter.

10. NITRIFICATION

Nitrification is an aerobic process involving the production of nitrates from ammonium salts. It is the work of autotrophic bacteria. The nitrogen transformation in soil may be briefly depicted as follows :

Organic nitrogen $\rightarrow NH_3$ + *Nitrosomonas* $\rightarrow NO_2$ + *Nitrobacter* $\rightarrow NO_3$

NO_2 + Energy; NO_3 + Energy

$\leftarrow$ Ammonification $\rightarrow$ $\leftarrow$ Nitrification $\rightarrow$

Nitrification occurs in at least two steps ; ammonia to nitrite and nitrite to nitrate. These two steps are carried out by different groups of bacteria. The nitrite formation is carried out by *nitrosomonas* while the

nitrate formation is brought about *nitrobacter*. The net reactions are as follows :

$$2\ NH_3 + 3\ O_2 \rightarrow 2\ HNO_2 + 2\ H_2O + 79 \text{ Calories}$$
$$2\ HNO_2 + O_2 \rightarrow 2\ HNO_3 + 43 \text{ Calories}$$

The conversion of NO_2 to NO_3 is faster than that of NH_3 to NO_2. This is desirable because any accumlation of NO_2 would be toxic to plants.

The source of carbon for these organisms is carbon dioxide or the bicarbonate ion. The *nitrosomonas* group oxidises 35-70 moles of ammonia and the nitrobacter group 70-100 moles of nitrite per mole of carbon assimilated. The enzymes responsible for these oxidations are being investigated. The probable course of oxidation is :

$$\underset{\text{Ammonia}}{NH_3} \rightarrow \underset{\text{Hydroxylamine}}{NH_2OH} \rightarrow \underset{\text{Hyponitrite}}{HON{-}NOH} \rightarrow \underset{\text{Nitrite}}{NO_2} \rightarrow \underset{\text{Nitrate}}{NO_3}$$

The presence of hyponitrite as an intermediate product has not been definitely established.

The factors affecting nitrification are :

Soluble organic matter : This depresses nitrification but the presence of heterotrophic organisms keep soluble organic matter at a low level. In a way, heterotrophs and autotrophs work their for natural benefit.

Soil reaction : The nitrification is slow in alkaline and acid soils and is favoured by a neutral soil reaction. The liming of acid soils provides a favourable medium for nitrification, besides providing calcium as a nutrient.

Phosphate supply : Addition of phosphate is known to favour the process of nitrification. The efficiency of super-compost (compost prepared with superphosphate) can also be explained on the principle that it helps to provide large quantities of available nitrogen.

Oxygen requirement : The nitrifying organisms are aerobic and have a high requirement for oxygen and are therefore favoured by well-drained, aerated soils.

Soil texture : Nitrification in soil occurs mainly at the soil colloid surface where NH_4^+ is adsorbed and where the bacteria adhere. Nitrification is favoured in loamy or clay loam soils and is slower in sandy soils.

Moisture : The presence of moisture is essential for all life processes and the same is true for microbial activity. Fifty per cent of water holding capacity has generally been found to be favourable for nitrification.

Temperature : The production of nitrates is greatest at 37°C and the process stops at 5°C and 55°C. Nitrifying power is influenced by

manures and fertilisers. Soils from Pusa permanent manurial experimental plots (started in 1932 in India) have been tested for their power to nitrify ammonium sulphate at 30 mgm. N per 100 gm. soil. The results are reported in Table 12.2. The data relate to 1946-47. The use of phosphate in combination with nitrogen has maintained the nitrifying power, and continuous use of NP fertilisers (nitrogen+phosphate) has maintained the fertility at a high level which is slightly higher than with farmyard manure. The no-manure treatment has given very poor nitrifying capacity.

A high rate of nitrification was found to be positively correlated with the uptake of nitrogen and crop yield.

TABLE 12.2

EFFECT OF MANURING ON NITRIFYING POWER IN NEW MANURIAL SERIES (PUSA, BIHAR STATE, INDIA) (1946-1947)*

Treatment	Nitrifying power of soil at the end of 4 weeks. (mgm. NO_3-N per 100 gm. soil)
No manure	4.8
Farmyard manure at 40 lbs. N	27.0
Rape cake at 40 lbs. N	25.8
Ammonium sulphate at 40 lbs. N	21.6
Potassium sulphate at 50 lbs. K_2O	15 6
Superphosphate at 80 lbs. P_2O_5	19.2
Potassium sulphate 50 lbs. K_2O+superphosphate 80 lbs. P_2O_5	21.6
Ammonium sulphate 40 lbs. N+superphosphate 80 lbs. P_2O_5+potassium sulphate 50 lbs. K_2O	28.8
Ammonium sulphate 40 lbs. N+superphosphate 80 lbs. P_2O_5	28.8
Ammonium sulphate 40 lbs. N+potassium sulphate 50 lbs. K_2O	15.6

**Source* : P Sinha, *Jour. Ind. Soc. Soil Sci.* 5(4) 205-211 1957

11. DENITRIFICATION

The process which involves conversion of soil nitrate into gaseous nitrogen and/or nitrous oxide is called denitrification.

Gayon and Dupetit (1866) showed that denitrification was due to the action of a number of bacteria. They isolated and described in detail the physiology of *Bacterium denitrificans a* and *b*. The strain *a* produced both N_2O and nitrogen on a synthetic medium, whereas strain *b* produced only nitrogen and did not consume all the nitrate. Later other bacteria belonging to genera *Pseudomonas*, *Micrococcus* and *Bacillus* were discovered.

The rate of denitrification varies in different soils depending primarily on the moisture content, pH of the soil, organic matter content, and structure.

Denitrification is favoured by an increase in the degree of anaerobic conditions. Water-logging by flooding or excessive rain, e.g., in rice fields will increase nitrogen losses due to denitrification. Nitrate fertilisers, therefore, should not be used in rice fields. No denitrification occurs at a water content of less than 60 to 70 per cent of maximum water holding capacity. A high water content inhibits the diffusion of oxygen in the soil.

The denitrification process is favoured by relatively high pH values. At pH below 6 the reduction of nitrous oxide is inhibited. The optimum temperature for denitrification is 60—70°C. A high content of easily oxidisable organic matter favours denitrification. Any structural condition which inhibits the diffusion of oxygen will induce denitrification.

12. BIOLOGICAL NITROGEN FIXATION

Nitrogen fixation is one of the three most important natural processes. The other two are photosynthesis and respiration. Biological nitrogen fixation is probably one of the chief sources of nitrogen for soils. But for this source, the soil would be poor and unfit to nourish crops, as the removal of nitrogen by crops from soils is in astronomical figures.

There are two main classes of organisms that fix atmospheric nitrogen, nonsymbiotic and symbiotic. Of the nonsymbiotic group, *Azotobacter* and *Clostridium* are the most important. The symbiotic group are the legume bacteria of the genera *Rhizobium*.

Nonsymbiotic nitrogen fixing bacteria : There are a number of organisms (nonsymbiotic) that fix nitrogen, but *Azotobacter* and *Clostridium* are the most important. Beijerinck (1894) discovered a heterotrophic organism called *Azotobacter chroococcum*, which utilizes soluble carbohydrates and fixes atmospheric nitrogen. *Azotobacter* is the most important nonsymbiotic organism responsible for nitrogen fixation. It is strongly aerobic and oxidizes carbohydrates and other sources of carbon completely to CO_2 and water. The efficiency of nitrogen fixation usually does not exceed 15 to 20 mg. of nitrogen per gram of carbohydrate. *Beijerinckia* species are more tolerant of acid soils.

Azotobacter is favoured by a neutral reaction, ample phosphate, aerobic conditions, and a moist and well-drained soil. *Azotobacter* is susceptible to a deficiency of phosphate. This property has been utilized to detect the

nutrient deficiency in soil. Several workers have noticed appreciable nitrogen fixation by *Azotobacter* especially in phosphate fertilised fields. Other nutritional requirements of *Azotobacter* are vitamin B, nucleic acids, calcium and molybdenum. Manganese compounds also accelerate nitrogen fixation.

In recent years, *Azotobacter* inoculation in soil or on seed has been tried by Russian workers who have reported beneficial results. All such experiments have not proved fruitful, but if an attempt is made to find the optimum conditions for introduction of *Azotobactor* to a new environment, better results can be expected. Recent experiments in India have shown that *Azotobacter* bacterization with earthworm casts provide favourable conditions for the growth and activity of *Azotobacter*.*

The statement that *Azotobacter* is favoured by a neutral soil reaction is confirmed by research conducted in south India, given in Table 12.3.

TABLE 12.3

THE RELATIONSHIP BETWEEN pH AND ABUNDANCE OF *AZOTOBACTER* IN SURFACE SOILS, MADRAS STATE, INDIA*

pH	Population in Numbers per Gram of Soil (Dry Basis)**
5.5	204
6.5	442
6.7	538
6.9	342
7.1	1,080
7.5	163
8.3	17

*G Rangaswami and K.V. Sadasivami. *Studies on the Occurence of Azotobacter in Some Soil Types*. Journal of the Indian Society of Soil Science. Vol. 12, No. 1, March, 1964

**The number are averages for the four species : *A. Chroococcum, A. Indicus, A. Agilis, and A. lacticogenus.*

Clostridium pasteurianum works in anaerobic conditions. This organism is less efficient than *Azotobacter*. About 2-3 mg. nitrogen are fixed per gram of carbohydrate fermented. Low efficiency of *Clostridium* can be explained on the basis that while anaerobic fermentation releases only a small amount of energy, aerobic changes produce tremendously large amounts of energy which help to fix more nitrogen.

*Bhat, J.V., *Bacterization Experiments with Azotobacter*. Proceedings of Symposium on Radio Isotopes, Fertilizers, and Cowdung Gas Plant. Indian Council of Agricultural Research, New Delhi, India. 1959.

Fig. 12.1 An example of legume nodules is shown here as large irregular clusters on plant roots which house the symbiotic bacteria, *Rhizobium* species (*Courtesy Nitragin Company, U S A.*)

Symbiotic nitrogen fixing bacteria : From the standpoint of agriculture, the most important nitrogen fixing agent is associated with root nodules of leguminous plants which have been used for improvement of soil fertility from ancient times. The root nodule bacteria are classified as *Rhizobium* sp. (after genus *Rhizobium*). Usually certain strains form nodules on a limited group of plants. Such a collection of strains is called a cross inoculation group, e.g., alfalfa or clover group. Six species of *Rhizobium* have been recognized in this group of bacteria. (See Figure 12.1.)

Species Name	*Group Name*	*Crops*
Group 1 *R. meliloti*	Alfalfa group	Lucerne, sweet clover
Group 2 *R. trifolii*	Clover group	White clover
Group 3 *R. leguminosarum*	Pea group	Garden, field, and sweet pea ; broadbean, lentil
Group 4 *R. phaseoli*	Phaseolus group	Garden and kidney bean
Group 5 *R. Japonicum*	Soyabean group	Soyabean
Group 6 *R. lupini*	Lupin group	Annual and perennial lupines
Group 7 *R.* (Unnamed species)	Cowpea group	Cowpea, lima bean, groundnut

Group V, VI and VII are not as distinct as the others because under certain conditions, *R. Japonium* can infect and form nodules on certain plants of the cowpea group and the *Rhizobium* species for the cowpea group may form nodules on soyabean.

The species of the first four groups are effective only on the crops belonging to the particular groups. Whenever any leguminous crop is to be introduced in a new area, the seed should be inoculated with the proper culture before sowing, as otherwise poor yields would be obtained in the first year of introduction. In the absence of the proper *Rhizobium* culture, the seed can be mixed with the soil obtained from an area where the particular group of legumes grow well. The artificial inoculation with *Rhizobium* species leads to increased yields and is therefore an important cultural practice.

Leguminous crops can add nitrogen to the soil by addition of roots, nodules, and by excretion of soluble nitrogen compounds, possibly ammino acids like aspartic acid and B alamine. This excretion is known to occur particularly when nitrogen fixation takes place more rapidly. There are a few instances of nonlegumes that are capable of living symbiotically with nitrogen-fixing bacteria. Alder shrubs and trees (*Alnus* species) are an example of a nonlegume genera of plants that contain symbiotic nodules on their roots that are capable of fixing more than 100 pounds of nitrogen per acre per year.*

13. MAGNITUDE AND SIGNIFICANCE OF NITROGEN FIXATION

Millions of tons of nitrogen are being removed by crops from the soil. If nitrogen is not returned to the soil, life would become impossible. The amount of fixed nitrogen by way of fertilisers and manures is still small as compared to the nitrogen requirement of crops. The biological nitrogen fixation forms one of the chief sources for replenishing soil nitrogen.

The amount of nitrogen fixed by leguminous plants may vary from 0 to 200 pounds of nitrogen per acre in one growing season. On an average, 50 to 100 pounds of nitrogen may be fixed, depending upon the crop, soil, and moisture availability. The relative magnitued of nitrogen fixed, taking lucerne as 100, has been worked out and is given in Table 12.4.

*Goldman, Charles R. *The Contribution of Alder Trees (Alnus tenuifolia) to the Primary Productivity of Castle Lake, California.* Ecology Vol. 42, No. 2, 1961.

TABLE 12.4

FIXATION OF NITROGEN IN ALLAHABAD (INDIA) SOIL IN 180 DAYS

Allahabad Soil+wheat straw	N fixed, lbs. per acre.
In Light	117.6
In Dark	43.7
Allahabad soil+wheat straw+0.1% P_2O_5	
In Light	215.2
In Dark	90.0

Source : Dhar, N. R., *Nitrogen Problem.* Presidential Address to the 48th Indian Science Congress, Roorkee, 1961.

The amount of nitrogen in legume when green manured represents the nitrogen it has taken from the soil and from air. The relative amounts derived from each of the sources are difficult to determine but it is roughly estimated that two thirds is derived from the air and one third from the soil. The nodule bacteria are able to utilize the combined nitrogen of soil as well as the gaseous form. If the soil is rich in available nitrogen, the nodule bacteria utilize the fixed soil nitrogen by preference and the gain of nitrogen by biological fixation is small. If the soil is very poor in nitrogen, a small amount of nitrogen fertiliser (10 lb N per acre) is greatly beneficial in obtaining higher yields of legume crops.

The work of Parr and Bose, Sen and Sundarrao, on Delhi soils has shown that the phosphate fertilisation of berseem clover (Egyptian clover) helped to increase the yield of green matter and left the soil enriched with nitrogen. Approximately for every one pound of phosphate (P_2O_5) given as superphosphate, 1-3 pounds of nitrogen are fixed by legumes. The gain in nitrogen is estimated at approximately 50 pounds per acre per growing season. The actual amount of nitrogen fixed (per pound of P_2O_5) would vary in different soils depending upon whether the soil was initially deficient in available soil phosphate or is adequately supplied.

The use of ammonium phosphate or a small dose of nitrogen along with superphosphate (in India) has given best results in increasing yields of berseem clover, groundnut, and other legumes.

Among the leguminous crops tried, berseem clover has given the best response to phosphate fertilisation. Response of other crops has also been significant but to a lesser degree.

The soils of Sind and Punjab (West Pakistan) have tremendous power of fixing nitrogen by nonsymbiotic organisms. One of the reasons attributed to the beneficial effects of fallowing is high nitrogen fixing capacity. Hutchinson, reporting the work of Wilsdon and Barkat Ali on Lyallpur soils, reported that the nitrogen fixed amounted to as much as 30 per cent of the

nitrogen content of the soil. In certain years, the amount of nitrogen fixed was low. But with even 10 mgm. nitrogen fixed per 100 gm. soil, it amounts to 200 pounds of nitrogen per acre. This addition took place

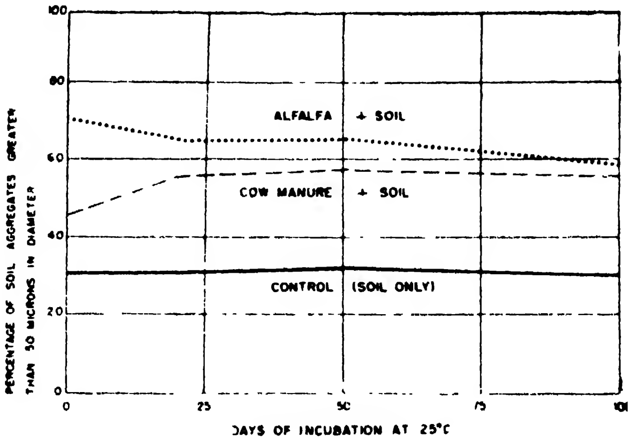

Fig. 12.2 A comparison of the aggregating influence of bacteria, actinomycetes, and fungi when incubated with sterile Gila clay at 26°C for 21 days.(D.S. Hubbell and Glen Staten, *Studies on Soil Structure*. New Mexico Agr. Exp. Sta Technical Bul 633. 1951.)

during a fallow season after a wheat crop. The factors for high rates of fixation need to be investigated so that such knowledge could be used for soils with low nitrogen-fixing ability.

Fixation of nitrogen by mixed flora and *Azotobacter* isolated from tank silts of West Bengal (India) has been reported by Sen*. In all cases, the nitrogen fixation by mixed flora was higher than that by *Azotobacter*. The amount of nitrogen fixed per gram of mannite in 2 weeks varied from 4.4 to 13.7 mgm. N with mixed flora and 2.0 to 7.4 mgm. N with *Azotobacter*.

14. SOIL MICROFLORA AND SOIL STRUCTURE

Bacteria, fungi, and actinomycetes aid in the development of desirable soil structure by their secretions of gummy substances that are not water-soluble. A comparison was made of the relative amount of good soil structure that was produced by each of these three groups of plants, and the results are graphed in Figure 12.2. From Figure 12.2 it is obvious that bacteria are responsible for the creation of the least relative amount of large soil aggregates. Whereas actinomycetes are 17 times more efficient than bacteria, fungi are the best of all for this purpose.

* Sen, Abishwar, *Studies on Nitrogen Fixation by Azotobacter Occurring in Tank Silts.* Indian Jour. Agri. Sci. 25(2) 131-142 (1955).

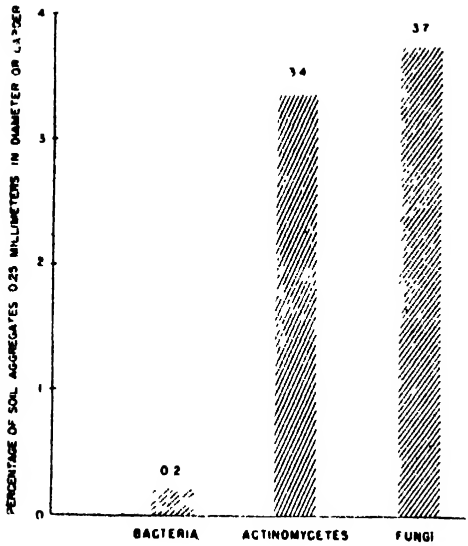

Fig. 12.3 A comparison of the soil-aggregating effect of alfalfa and cow manure with time on Declo loam. (J. J. Doyle, *Organo-Clay Relationships in Soil Aggregate Formation*, Ph. D. Thesis, Ohio State University, 1952.)

It is of interest to compare the soil-aggregating influence of cow manure and alfalfa when added to the soil. Figure 12.3 portrays these data for a Declo loam in Ohio. With soil only, the percentage of soil aggregates greater than 50 microns in diameter was approximately 30 throughout the entire incubation period of 100 days. With cow manure the percentage of large aggregates was 46 the first day and rose to a peak of 56 on the 50th day of incubation, then dropped slightly on the 100th day. Alfalfa gave the best results, with 69 per cent large aggregates in the beginning and declining slowly to 58 per cent on the 100th day of incubation.

15. MICROBES AND SOIL FERTILITY

There are numerous groups of microbes inhabiting the soil. Though they form only a very small part of the soil mass, they are responsible for many of the chemical transformations in soil. They play a great role in building soil fertility and maintaining the nutrients in an available form. The value of bulky manures would be negligible but for the activity of microbes. The microorganisms which utilize carbonaceous material for their energy transform organic nitrogen, phosphorus, and sulphur compounds into simple inorganic compounds which are utilized by higher plants. Many mineral nutrients including micronutrients held in an unavailable organic combination are also released in an available form by microbial decomposition.

The activity of microorganisms that decompose organic matter is responsible for other beneficial changes. For example, organic acids and carbon dioxide that are released by decomposition make insoluble phosphates and other unavailable compounds more available to plants.

The addition of sulphur to alkali soils is beneficial only because of the activity of sulphur-oxidizing bacteria which produce sulphuric acid. The

latter neutralizes the alkalinity. The addition of sulphur with bulky manures is particularly efficient.

The role of nitrogen-fixing organisms in the recuperation of nitrogen reserves in soil has been discussed. Both symbiotic and nonsymbiotic organisms are responsible for maintaining the nitrogen economy of soils. The phosphate manuring of legumes, e.g., berseem clover and *sannhemp*, particularly on phosphate deficient soils, has helped to produce better crops with vigorous nitrogen fixation.

In recent years, Russian workers and in India, Sunderarao, Sen, and Paul have made use of phosphate solubilizing bacteria (Russian and Indian strains) in the maintenance of available forms of phosphate. The results show that phosphobacterin is likely to succeed in areas where available phosphate is low provided there is an adequate application of organic matter to the soil.

Like higher plants, microorganisms have similar nutrient requirements. The deficiency of any nutrient would limit the growth and activity of an organism. Using this principle, several organisms like *Azotobacter* and *Aspergillus niger* have been used to test for any possible soil deficiencies.

Life would be impossible without microbial activity. All the dead mass, garbage, and diseased material, when added to the soil is transformed into useful substances. Pathogenic organisms are killed by substances produced by soil microorganisms. The preparation of antibiotics is largely dependent upon soil microorganisms. The antibiotics have been used with varying degree of success in the control of plant diseases.

16. PHOTOCHEMICAL REACTIONS

Dhar and his co-workers in India have shown that photochemical processes are predominantly responsible for nitrogen transformation. The process is activated by the addition of humic acid and zinc oxide. Organic materials like dung and straw not only increase plant nutrients to the extent they are contained in them but help to fix nitrogen during oxidation of carbonaceous residues. An interval of 3 to 6 months is needed for this purpose.

Dhar (1961) has brought out the importance of photochemical nitrogen fixation. He has reported larger additions of nitrogen to soils in the presence of light than in the dark. The addition of wheat straw or molasses increased the nitrogen fixation, particularly when combined with phosphate application. Rock phosphate, basic slag, and tricalcium phosphate have been used as phosphate sources. The figures of nitrogen fixation with an Allahabad, Uttar Pradesh, India, soil are given in Table 12.4.

Dhar has quoted the results of G. Bjalfue of the Royal College of Agriculture Sweden, who observed more nitrogen fixation in light than in the dark by incorporating straw with soil or sand, and that calcium phosphate increased the amount of nitrogen fixation. The details of mechanisms by photochemical processes remain to be established.

Desai and Fazaluddin, working with Lyallpur soils in West Pakistan, have also reported the importance of photochemical reactions particularly in photo-nitrification. Organic matter, zinc, bismuth, and mercury salts possess striking catalytic power. A few European workers, de' Rossi in Italy and Corbet in England, support this view of photo-nitrification. Russell, Waksman, and other workers believe that photochemical transformations involving nitrogen are at best of minor importance and that biological changes are most important in bringing about nitrogen transformations.

The fact that the nitrogen fixation occurs in the dark proves the role of biological nitrogen fixation. The difference lies in greater emphasis and importance attached to photochemical reactions in nitrogen fixation by Dhar and co-workers.

It is now known that certain photochemo-autotrophs like sulphur bacteria, purple bacteria, *rhodospirillum*, and a blue-green algae in water-logged paddy soils, are present in the soil. These organisms are also responsible for nitrogen fixation which is expected to be accelerated due to the presence of light.

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CHAPTER THIRTEEN

MANURES, COMPOST, GREEN MANURES, SAWDUST AND SEWAGE

"*Rich in manure, rich in fruit*"

ATHARVA VEDA SAMHITA, CIRCA 350 B.C.

"*No fodder, no cattle ; no cattle, no manure ; no manure, no crop.*"

ANCIENT TAMIL PROVERB

Under constant cultivation, our soils are losing organic matter faster than it can be replaced. A decrease in soil organic matter results in compact soils, shallow roots, increased drought, and cloddy soils. Soil organic matter can be maintained by the liberal use of farmyard manures, compost, green leaf manuring, and by including legume crops in rotation.

One of the factors that contributes most to the fertility of soils is the content of organic matter. Organic matter is a good source of plant nutrients. It provides food for soil microorganisms and the by-products of decomposition help to bring the mineral constituents of soil into solution. Organic matter modifies the physical properties of the soil, (such as structure by promoting granulation) and increases moisture-holding capacity and permeability. Soil organic matter improves the physico-chemical properties of soil such as cation exchange, and buffer action.

Because of these beneficial effects of soil organic matter, organic manures should be used wherever available. Farmers all over the world know the value of farmyard manures but they need help in learning to use them more efficiently. For example, if organic matter such as straw is added to the soil without having been first decomposed, it would create a shortage of available nitrogen due to microbial activity; in this case the following crop is likely to suffer.

I. FARMYARD MANURE

Farmyard manure includes the solid and liquid excreta of livestock, generally mixed with a small amount of litter such as straw which has been used as bedding for the animals. The plant nutrients : nitrogen, phosphorus and potassium in the excreta of various animals come from the feed eaten by the animals. The average composition of fresh animal excreta is given in Table 13.1. The urine of all animals is rich in nitrogen and potassium and poor in phosphorus, as compared to the dung.

TABLE 13.1

AVERAGE COMPOSITION OF FRESH EXCRETA OF FARM ANIMALS

Source		N Per cent	P_2O_5 Per cent	K_2O Per cent
Cows & Bullocks	Dung	0 30	0 20	0.10
	Urine	1.00	Trace	1 40
Sheep & Goats	Dung	0.75	0.50	0.45
	Urine	1.35	0.05	2.00
Horses	Dung	0.50	0 30	0.50
	Urine	1.35	Trace	1.25
Pigs	Dung	0.60	0.50	0 50
	Urine	0.40	0.10	0.30

The Care of Manure: The common practice of storing farmyard manure on cultivators' fields is very defective. Dung and litter are usually collected each morning and put in heaps in open spaces. The manure heap remains exposed to rain and sun and considerable loss of nutrients occurs. This is illustrated in Figure 13.1.

Approximately one half of the fertilising value of manure is lost during several months of exposure to the weather. Upon decomposition, a considerable amount of ammonia is lost by volatilization. No systematic attempt is made at collection of urine which is rich in nitrogen and potassium.

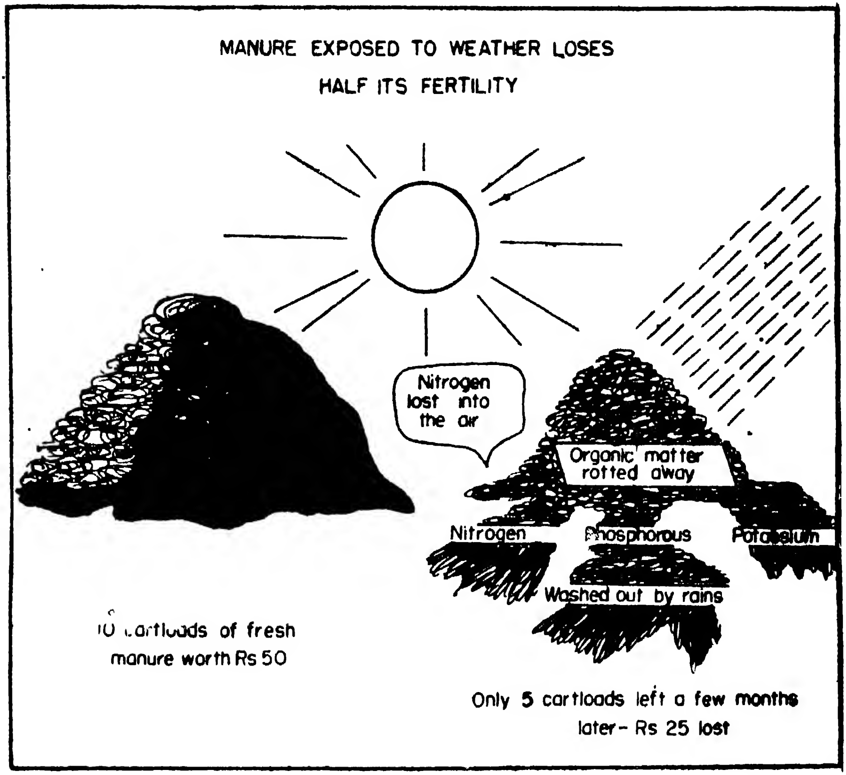

Fig. 13.1 Approximately half of the nutrients in fresh manure is lost by weathering before it is spread on the land. (*Illinois Agr. Extension Service Cir. 595, 1953*)

Adequate bedding to absorb all the urine, better method of storage, and reinforcement with superphosphate, all help in reducing losses from manure. Of special importance in the care of manure is keeping it protected from weather, until it is spread on the fields. (Figure 13.1.)

Preservation of Farmyard Manure: The following method has been recommended by Acharya for preparing good quality farmyard manure and to avoid high nutrient losses. The manure preparation should be carried out in trenches of 20-25 ft. long, 5-6 ft. breadth and 3-3½ ft. deep. All suitable dry litter and farm refuse should be kept near the cattle shed and about 5 pounds (mixed with earth) should be spread under each animal in the evening for absorption of urine. The litter should be localized in the areas where urine generally drops and soaks into the ground. Each morning urine-soaked litter and dung should be well mixed and taken to the manure trench. A section of 3 feet length of the trench is taken up from one end

for filling with the daily collections of refuse. When the section is filled to a height of 1½—2 ft. above ground level, the top surface is plastered with a cowdung-earth slurry, after which the next 3 ft. length of the trench is filled.

When the trench is completely filled, a second trench is made and filled in a similar manner. In about 3 months the manure is ready for use. Normally by the time the second trench is filled, the manure would be ready for use in the first trench. The number of trenches needed would, however, depend upon the number of animals. About 2 such trenches would be needed for 3-4 head of cattle. It is possible to prepare by this process 250-300 cubic feet of manure (5-6 metric tons or 8-10 cartloads) per year per head of cattle.

Composition of Farmyard Manure : The composition of manure depends upon several factors; the more important ones are (1) kind of animal (2) feed of animal (3) age of animal (4) manner of storage and (5) nature of litter used. On an average the manure prepared by the above method usually contains 0.8% nitrogen, 0.3% phosphorus (P_2O_5) and 1% potassium (K_2O). Approximately 60 per cent of the nitrogen is contributed by the solid portion (dung and straw) and the other 40 per cent comes from the liquid portion. By contrast, nearly all of the phosphorus (99 per cent) is contributed by the solid portion. Sixty per cent of potassium is contributed by the liquid portion and 40 per cent comes from the solid part.

2. COMPOST

Compost can be prepared from a variety of refuse materials available on farms, in village surroundings, or in urban areas. Farm compost can be made from straw, sugarcane refuse, chaff, rice hulls, forest litter, weeds, leaves or miscellaneous crop residues. The compost pit is usually 20-25 feet long, 5-6 feet broad and 3-3½ feet deep.

The straw material for making compost could first be used as a bedding for cattle to conserve urine ; also a method could be devised to collect or drain urine directly into the compost pit. A good practice to follow is to first form a layer of plant residues in the pit about 12 inches deep. This layer is moistened with a slurry of cowdung and water, a suspension of water and previously-prepared compost, or water and earth. A second layer (12 inches thick) of the mixed refuse is then spread over and moistened with slurry; and the operations are repeated until the heap rises to a height of about 1½ to 2 feet above ground level; then the top is covered with a thin layer of

Fig. 13.2 This composit in Central India is now being dug and taken to the field to increase crop yields.

moist earth. After 3 months of decomposition the material should be well mixed, moistened, and again covered with earth. After another month or two, the manure is ready for application to the field (See Figure 13.2.)

3. REINFORCING MANURE

Superphosphate is used to reinforce manure for three primary purposes :

1. To reduce losses of nitrogen as ammonia.
2. To increase the percentage of phosphorus in manure to make it a better-balanced fertiliser.
3. To increase the efficiency of phosphorus utilization in soils that tend to tie up phosphorus.

It is recommended that two pounds of 16 per cent superphosphate be applied per day in the drain behind each cow. If this is not done, 50 pounds of superphosphate per ton of manure can be added after the manure is in a pile. Hydrated lime, ground limestone, and borax may be added to manure to reduce odors and to control flies.

Many soils have a very high capacity for making phosphorus fertiliser quickly unavailable to plants. One way to reduce this fixation is to apply the phosphorus fertiliser directly to manure. The organic matter in the manure supplies citrates, tartrates, oxalates, and other similar compounds which combine with iron and aluminium compounds more readily than with phosphorus. The result is a tie-up of iron and aluminium by the organic materials and an increase in availability of phosphorus. These substances are known as *chelates*.

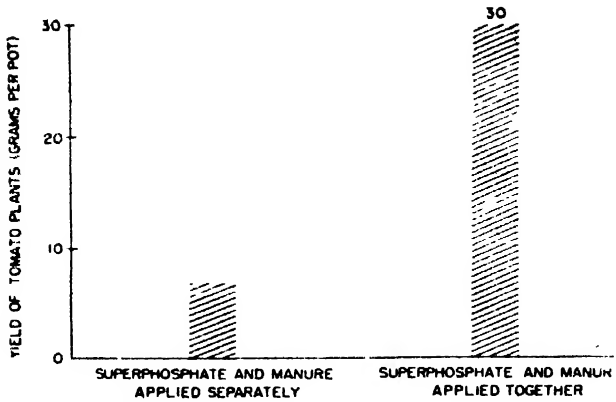

Fig. 13.3 The yield to tomato plants when superphosphate was applied separately as compared with the yield when superphosphate and manure were applied together (All superphoshate was applied at the rate of 200 pounds of P_2O_5 per acre, and manure at the rate of 20 tons per acre) (A.R. Midgley and David E. Dunklee, "*The Availability to Plants of Phosphates Applied with Cattle Manure*", Vermont Agr. Exp. Sta. Bul. 525 1945.)

An application of this principle is presented graphically in Figure 13.3. Superphosphate mixed with the soil, the manure being applied later, produced 7 grams of dry weight of tomato plants per pot. But when the superphosphate was mixed with manure and then applied to the soil, 30 grams of dry weight resulted. The organic matter in the manure combined with soluble iron and aluminium, thus reducing a tie-up of iron and aluminium with phosphorus. As a consequence, more phosphorus was available for plant growth. This research was conducted in Vermont (U.S.A.).

4. MANURE AND GAS PRODUCTION

A simple type of plant for anaerobic digestion of cowdung and litter has been devised at the Indian Agriculture Research Institute, New Delhi, as a result of the work of Desai, Acharya, Idnani, and others. This plant yields a good quality of manure as well as a combustible gas useful for lighting and cooking purposes. This plant is shown in Figure 13.4.

The plant is known as the Gobar Gas Plant and consists of a digestion tank and a gas holder. Cowdung slurry is added daily to the digestion tank and spent slurry overflows from the top of the well and collects in a

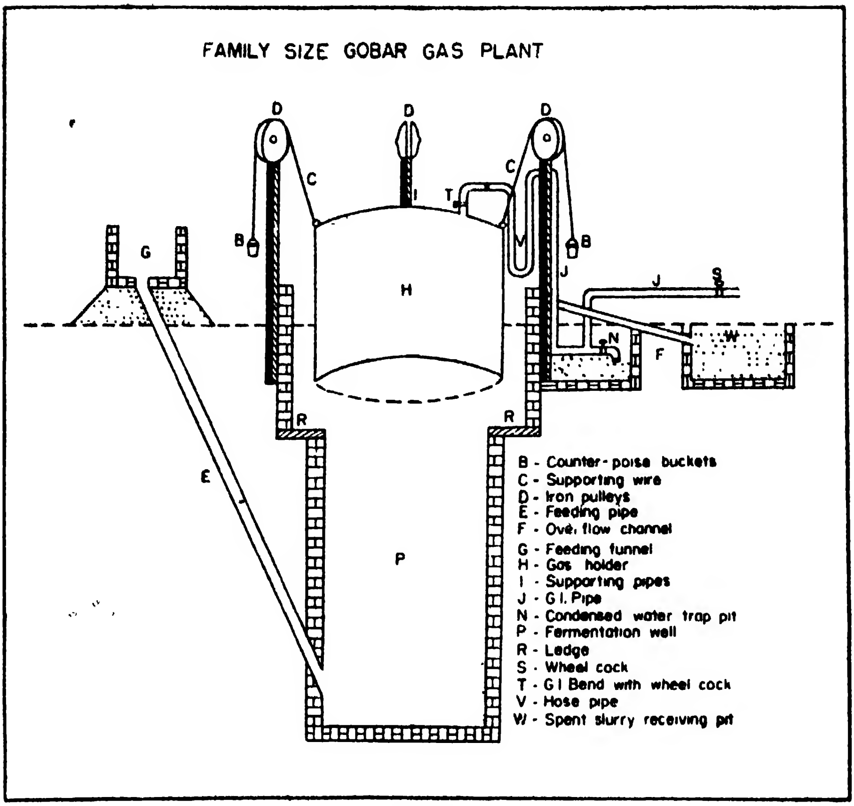

Fig. 13.4 Family Size Gobar Gas Plant. (*Source : I.A.R.I., New Delhi, Information Leaflet, 1962*)

pit from which it is periodically removed and added to the manure pit. The production of gas varies from about 1/2 cu. ft. per lb. of cowdung in the cooler months to about 3/4 cu. ft. per lb. of cowdung in the hotter months. The gas consists of about 50-60 per cent methane, 30-40 per cent carbon dioxide and about 10 per cent hydrogen. It possesses a caloric value of about 650 BTU per cu. ft., as compared to about 400-500 BTU per cu. ft. or gas prepared from coal and supplied in cities such as Bombay and Calcutta.

A family possessing 4-5 head of cattle can prepare about 70-75 cu. ft. of combustible gas per day and get about 4-8 tons of air-dry sludge per year. This sludge contains about 1.2 to 1.5 per cent nitrogen and is superior to fresh farmyard manure which contains a lower percentage of nitrogen.

5. NUTRIENTS IN FEED AND MANURE

From the feed, cattle return a large percentage of plant nutrients to the manure. When grain is fed to animals, approximately 75 per cent of the

WHAT BECOMES OF FERTILITY IN FEED?

Nutrients	100 Bushels of Corn Contains (lbs.)	Animals Retain (lbs.)	Returned in Manure (lbs.)	(%)
N	100	25	75	75
P_2O_5	39	8	31	80
K_2O	22	2	20	90

Fig. 13.5 From 75 to 90 per cent of the N, P_2O_5 and K_2O in corn (maize) is returned to the soil in manure. (C.M. Linsley, *Manure is Worth Money. It Deserves Good Care*, Illinois Agr. Ext. Service Cir. 595, 1953.)

nitrogen, 80 per cent of the phosphorus (P_2O_5), and 90 per cent of the potassium (K_2O) is excreted as manure. (See Figure 13.5.)

6. GREEN MANURE CROPS

By ploughing under green leguminous plants, roots, and leaves, not only the plant nutrients taken by the green manure crop are returned to the soil but the nitrogen fixed by the bacteria living in nodules of leguminous crops is also added to the soil and is a net gain. Besides the addition of organic matter, the freshly decomposing organic matter provides a favourable environment for many physical, chemical, and biological activities.

The best known green manure crops are *sannhemp* (*sanai*), *dhaincha*, *berseem* clover and pulses such as *urd*, *moong*, *guar*, *lobia*, and *arhar*. *Sannhemp* is the most commonly used green manure in India. *Sannhemp* does best on sandier soils where waterlogging is not likely to occur. It cannot compete with *dhaincha* on clay soils and in districts of heavy rainfall. *Sannhemp* grows very rapidly and overgrows all weeds. It decomposes in soil quickly and adds nearly 8000 kilos of green matter and about 40 kilos of nitrogen per hectare (0.5 per cent in green matter) 2/3 of which would come from the atmosphere.

Dhaincha can withstand severe drought and will also grow in badly drained land and in soils which are slightly saline. If there is sufficient

Fig. 13.6 Sannhemp (top) is the most popular green-manure crop in India. The second-most common green-manure is *dhaincha* (centre). At the bottom is the most common schrub, *Glyricidia maculata*, used as a source of green-leaf for green-leaf manuring.

moisture for the seed to germinate, the crop usually makes good growth and does not require any irrigation. It can be ploughed in within 2-3 months after planting. It provides nearly 7-8 thousand kilos of green matter and about 33 kilos of nitrogen per hectare.

Pulses and beans such as *urd*, *moong*, *guar*, *lobia*, and *matar*, are used as green manure crops on a small scale. *Berseem* clover is used as green manure with great advantage. Besides giving abundant green matter as cattle feed for the first 2 cuttings, the last cutting could be used for green manuring. *Glyricidia maculate*, a leguminous shrub, is used as the primary source for green-leaf manuring in India (See Figure 13.6.)

7. SAWDUST

There are large quantities of sawdust that could be used as bedding material to conserve urine, or for use in a compost. As a fertilising material, sawdust ranks very low. A comparison of its nutrient content with that of wheat straw and lucerne is given in Table 13.2. Sawdust contains 4 pounds of N, 2 pounds of P_2O_5 and 4 pounds of K_2O per ton of material, on an oven dry basis. Sawdust is richer than wheat straw only in its calcium content. Lucerne is from nearly ·5-15 times as rich with essential elements as is sawdust.

TABLE 13.2

THE PRINCIPAL PLANT NUTRIENTS IN SAWDUST, WHEAT STRAW AND LUCERNE HAY IN POUNDS PER TON OF DRY MATERIAL*

Organic Material	Nitrogen (N) (lb.)	Phosphorus (P_2O_5) (lb.)	Potassium (K_2O) (lb.)	Calcium ($CaCO_3$) (lb.)	Magnesium ($MgCO_3$) (lb.)
Sawdust	4	2	4	11	1
Wheat Straw	10	3	12	7	2
Lucerne	48	10	28	50	15

* F.E. Allison and M.S. Anderson, *The Use of Sawdust for Mulches and Soil Improvement*, U. S. D. A. Cir. 891, 1951.

Sawdust is a very satisfactory product as a bedding material. Experiments conducted at the Indian Agricultural Research Institute, New Delhi, by Idnani have shown that sawdust has a very high capacity for absorbing urine (480 ml. per 100 gm. of material), and on drying, very little loss of nitrogen occurred. Other materials tried were dry leaves, paddy husk, ash, and soil. Sawdust provides the best means of conserving urine. It has been estimated that the urine alone from 170 million head of cattle could contribute 3.74 million tons of nitrogen, 0.11 million tons of phosphorus (P_2O_5) and 3.91 million tons of potassium (K_2O). With single saturation, sawdust contains about 3-4 per cent nitrogen. On drying and reusing it, the sawdust absorbs more urine. With 3 such saturations, the nitrogen content may be increased to 9 to 10 per cent.

8. SEWAGE

The rapidly increasing population of cities is intensifying the problem of sanitation and sewage disposal. In the modern system of sanitation, water is used for the removal of human excreta and other wastes, and there is a considerable dilution of material.

Sewage has two components : (1) The solid portion, called sludge and, (2) the liquid portion called effluent or sewage water. Sludge produced from city sewage plants are of two general types (1) activated sludge (2) digested sludge.

Activated sludge is made by bubbling a large volume of air for several hours through raw sewage in the presence of aerobic bacteria. Digested sludge consists of anaerobic decomposition of the raw sewage in large open vats for at least two weeks.

Activated sludge is richer than digested sludge in all essential elements except manganese. Both kinds of sludge are especially high in percentage

of zinc. There is almost no potassium in either kind of sludge, because it is leached out by the large quantities of water used in their processing. (See Table 13.3.)

TABLE 13.3

ESSENTIAL ELEMENTS IN ACTIVATED AND DIGESTED SEWAGE SLUDGE*

Kind of Sludge	Nitrogen (N) %	Phosphorus (P_2O_5) %	Potassium (K_2O) %	Zinc (Zn) ppm	Copper (Cu) ppm	Manganese (Mn) ppm	Boron (B) ppm	Molybdenum (Mo) ppm
Activated	5.6	5.7	Trace	2,500	916	134	33	16
Digested	2.4	2.7	Trace	2,459	643	262	9	6

* Anderson, M. S., *Composition of Sewage Sludge as Influenced by Type of Disposal. System.* A Paper Presented Before the Soil Science Society of America, Davis, California, 1955.

Near many cities sewage is used for fertilising crops by irrigating directly with the effluent. Care must be taken, however, to avoid the spread of certain human diseases.

9. MANURE AND AVAILABLE WATER

At the Rothamsted Experiment Station near London, England, 14 tons of cattle manure per acre per year were applied for 100 years. A similar plot received no manure. The results show that the plough layer of the manured plot is capable of supplying 0.7 inch more of available water for crops than the plot which received no manure.

10. ORGANIC MATTER AND SOIL STRUCTURE

As organic matter decomposes, certain glue-like substances are released which tend to create more water-stable aggregates in the soil. This is desirable.

The aggregating influence of sawdust, cow manure, alfalfa (lucerne) hay, and wheat straw is presented by a line graph in Figure 13.7. These organic substances were incubated with a loam soil for a period of 200 days and their ability to stabilize soil aggregates larger than 50 millimeters in diameter was measured.

Wheat straw was most efficient in soil aggregation, followed by alfalfa, cow manure, and sawdust.

11. MANURES AND CROP YIELDS

Fertilisers usually furnish one or more of the nutrient elements, nitrogen, phosphorus, and potassium. They are used primarily for the inorganic

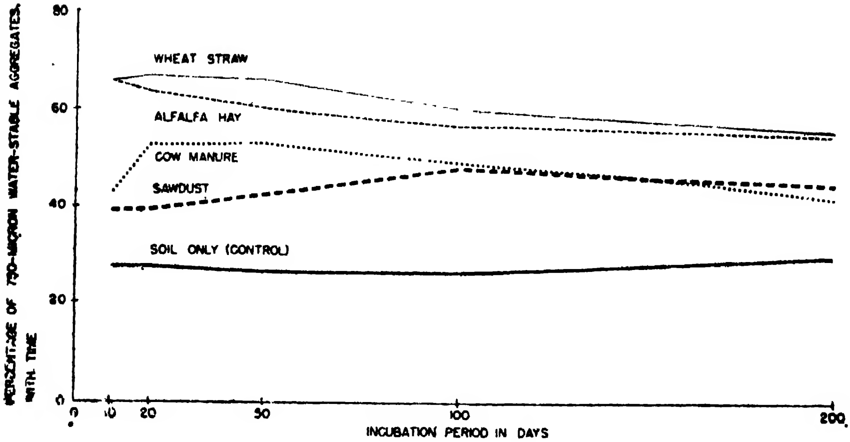

Fig. 13.7 The effect of certain organic materials on aggregation of Declo loam. (Each organic material was applied in concentrations of 2 per cent.) (J. J. Doyle, *Organo-Clay Relationships in Soil Aggregate Formation.* Ph.D. Thesis, Ohio State University, 1952.)

elements in them that are immediately available to plants or easily made available under favourable soil conditions. Bulky manures, including green manures, supply not only nitrogen, phosphorus and potassium but also many other essential nutrients required in small amounts by plant. It is because of micronutrient content that organic manures are an insurance against any possible mineral deficiency that may be created by the the use of single nutrient fertilisers. Of course, such deficiency can be prevented by the use of appropriate nutrients but all this involves a constant watch by the farmer, and extension and research workers as regards soil requirements. In this respect, organic manures are safest and should be used wherever available. Moreover, the application of compost may be particularly helpful in ameliorating saline and alkali soils.

All crops respond to use of bulky manures. The actual response varies with conditions. Response of 25-50 per cent in paddy yields has been obtained in India and Pakistan by the use of cattle manure at the rate of 40 lb. N per acre (other nutrients would of course be present). The response has been similar with wheat, sugarcane, and other crops. For sugarcane, farmyard manure at the rate of 100 lb. N per acre has been used. Cotton manured at the rate of 7,000 kilograms per acre increased the paddy yield by 45 per cent in Maharashtra State. Madhya Pradesh State recorded an increase of 20-69 per cent with the use of *sannhemp.* In West Bengal, green manuring with *sannhemp* and *dhaincha* increased the paddy

yield by 20 and 21 per cent, respectively. Andhra Pradesh has recorded an increase of 80-100 per cent with green manuring of *dhaincha* or *sannhemp*. Similar beneficial effects of green manuring have been obtained in all parts of India and Pakistan on paddy, wheat, sugarcane and cotton.

In Japan, compost is a highly important source of plant nutrients. In 1946, when supplies of chemical fertilisers were low, it provided 47 per cent of the nitrogen, 66 per cent of the phosphorus and 64 per cent of the potassium applied to Japanese soils. Compost is also used extensively in Taiwan.

The studies of Henry (1928) reported by Das (1949) on relative merits of manures and fertilisers for paddy in Burma are given in Table 13.4.

It is evident that cattle manure and oil cake gave equal or higher yields than fertilisers (NPK). The residual effects of organic manures are particularly clear. Amongst the fertilisers, only the superphosphate shows a pronounced residual effect.

It is difficult to assess the value of organic manures in a single year or in short term experiments; only long-term experiments can demonstrate the

TABLE 13.4

RESPONSE OF DIFFERENT MANURES AND FERTILISERS ON PADDY AT HMAWBI EXPERIMENT STATION, BURMA

Treatment per acre	Per cent increase over control (5 years)	Residual effect (per cent increase or decrease over control) (5 years)
Cattle manure at 30 lb. N	37.5	21.8
Cattle manure at 50 lb. N	52.3	34.5
Cattle manure at 70 lb. N	68.7	37.8
Cotton seed cake at 50 lb. N	54.8	29.2
Cattle manure at 30 lb. N + Superphosphate at 20 lb. P_2O_5	43 6	27.6
Cattle manure at 30 lb. N + Bone meal at 20 lb. P_2O_5	51.0	31.8
Bone meal at 20 lb. P_2O_5	26 5	9.5
Superphosphate at 20 lb. P_2O_5	36.3	15.3
K_2SO_4 at 20 lb. K_2O	5.0	–6.6
$NaNO_3$ at 30 lb. N	–17.0	–35.5
Ammonium sulphate at 30 lb. N + Superphosphate 20 lb. P_2O_5 + K_2SO_4 at 20 lb. K_2O	3[illegible].5	17.5
Ammonium sulphate at 30 lb. N	32.5	–25.5

Source: Das, S. *The Relative Importance of Organic Manures and Inorganic Fertilisers in Tropical Soils.* Indian Jour. Agr. Sci. 19, Part I, 41—59, 1949.

value of manures. The results of long-term experiment at Coimbatore, Madras State, India, show that the effect of farmyard manure on the first 36 crops was generally inferior to that of complete mineral fertilisers, but the average yields from the 37th to the 56th crop generally favoured the farmyard manure. The results are shown in Table 13.5.

TABLE 13.5

RESULTS OF PERMANENT MANURIAL PLOTS AT COIMBATORE MADRAS STATE, INDIA*

	No Manure, no fertiliser		Complete fertiliser		Cattle manure	
	grain	straw	grain	straw	grain	straw
			Relative		Yields	
From 1st to 36th crop						
Cholam (jowar)	100	100	292	191	295	192
Ragi	100	100	903	548	750	426
Wheat	100	100	246	230	171	191
From 37th to 56th crop						
Cholam (jowar)	100	100	336	165	384	202
Ragi	100	100	429	402	409	479
Wheat	100	100	377	306	461	370
Cotton (Seed Cotton)	100		133		191	

**Source :* Das, S., *The Relatives Importance of Organic Manures and Inorganic Fertilisers in Tropical Soil.* Indian Jour. Agi. Sci. 19, Part 1, 41—59, 1949.

TABLE 13.6

RESULTS OF PERMANENT MANURIAL PLOTS AT PUSA, BIHAR AVERAGE FOR 22 YEARS FROM 1908-09 TO 1929-30**

Plot No.	Treatment per acre	Maize	*Arhar*	Oats
		Pounds per acre		
1.	No Manure	658	959	649
3.	Farmyard Manure at 20 lb. N.	860	1027	882
5.	Rape cake at 20 lb. N	939	929	656
10.	Ammonium sulphate+Superphosphate+ K_2SO_4 to supply N,P,K, as in plot 3	677	740	948
12.	Green manure in cereal rotation	804	384	622
16.	Green manure+superphosphate to supply P_2O_5 as in plot 3	1338	813	1367

***Source :* Das, S., *The Relative Importance of Organic Manures and Inorganic Fertilisers in Tropical Soils.* Indian Jour. Agri. Sci. 19, Part I, 41-49, 1949.

Results of Pusa, Bihar State, India, permanent manurial trials have shown that NPK fertilisers were somewhat superior to cattle manure and rape cake at 20 lb. N per acre for the first 22 years. At the end of this period the doses of N, P_2O_5 and K_2O were increased and the farmyard manure and rape cake at 40 lb. N per acre showed superiority over NPK fertilisers even though the latter contained more P_2O_5 and K_2O. The results are shown in Tables 13.6 and 13.7. Such results could be attributed to improved soil

Fig. 13.8 On red soil in the 50 inch rainfall belt in central India, *desi* maize responds to manure but yields are higher with adequate fertilisation **Left :** *Desi* maize, plus farmed manure, only ; **Centre :** *Desi maize*, no manure, but 100 pounds per acre of N, 60 pounds of P_2O_5, and 30 pounds K_2O per acre ; Yield : 5,633 pounds of ear maize per acre. **Right :** Hybrid maize, no manure, and the same fertilizer as in the Centre ; Yield 7,470 pounds of ear maize.
Note : All yields are on a 15 per cent moisture basis. (*Courtesy Frank Shuman*).

conditions brought about by organic matter as well as the micronutrients added in the manures. (See Figure 13.8.)

Many workers have reported that farmyard manure supplemented with chemical fertilisers offer the best means of maintenance of soil fertility at high levels. Green manures in combination with superphosphate have given high yields and in some cases even higher yields than farmyard manure or NPK fertilisers. This is shown in Tables 13.6 and 13.7. There is no doubt that farmyard manure, compost, green manures, and crop residues are very valuable in maintenance of soil fertility and ensuring a better physical condition of the soil. Available supplies of farmyard manure and compost are, however, limited and there have been occasional failures of green manuring due to scanty rainfall. High priority has been given in India, Pakistan, and other countries of Tropical Asia to develop manurial resources. All possible effort should be made to maintain the soil organic matter at as high a level as is economically feasible. (See Figures 13.9 and 13.10.)

TABLE 13.7
RESULTS OF PERMANENT MANURIAL PLOTS AT PUSA, BIHAR
AVERAGE FOR 17 YEARS FROM 1930-31 TO 1946-47.

Plot No.	Treatment per acre	Maize	Peas	Barley	Wheat	*Arhar*
				Pounds per acre		
1.	No Manure	410	234	248	366	659
3.	FYM at 8000 lb. (40 lb. N+ 26 lb. P_2O_5+ 54 lb. K_2O)	1098	585	936	892	954
4.	FYM at 4000 lb.+rape cake at 20 lb. N (40 lb. N+21 lb. P_2O_5+35 lb. K_2O)	1298	525	883	810	809
5.	Rape Cake at 40 lb. N (40 lb. N+15 lb. P_2O_5+15 lb. K_2O)	1007	307	728	568	767
10.	Ammonium Sulphate at 40 lb. N+superphosphate at 80 lb. P_2O_5+K_2SO_4 at 50 lb. K_2O	769	493	1069	765	858
15.	Effect of green manure and leguminous crop in rotation	597	247	745	599	480
16.	As in plot 15 with additional application of superphosphate at 80 lb. P_2O_5	797	590	2063	1504	878

Note : FYM is farmyard manure.

Source : Das, S., *The Relative Importance of Organic Manures and Inorganic Fertilisers in Tropic Soils.* Indian Jour. Agr. Sci. 19, Part I, 41—59, 1949.

Fig. 13.9 Maize plants need more than cattle manure (*gai khaa*) for maximum growth. **Left :** *(control)* No fertiliser, no manure ; **Centre :** *(gai khad)*. Two double handsful of cattle manure per pot. **Right :** *(gai khad + NPK)*. Two double handsful of cattle manure plus of 1 thimbleful of ammonium sulphate plus 2 thimblesful of 16% superphosphate plus one thimbleful of 60% muriate of potash per pot. *(Courtesy Frank Shuman)*

Fig. 13.10 Crop residues should be left in and on the soil as much as possible to assist in maintaining soil organic matter. Here the crop residues are being removed for use as fuel.

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CHAPTER FOURTEEN

PLANT NUTRITION

"*An element is not considered essential unless a deficiency of it makes it impossible for the plant to complete its life cycle; such deficiency is specific to the element in question and can be prevented or corrected only by supplying this element; and the element is directly involved in the nutrition of the plant quite apart from possible effects in correcting some unfavourable microbial or chemical condition of the soil or other culture medium*".

D I ARNON, CALIFORNIA AGRICULTURAL EXPERIMENT STATION

Plants contain small amounts of 90 or more elements, only 16 of which are known to be essential to plants. It is of interest to note that iron, carbon, sulphur, copper, and zinc have been known since ancient times. Nitrogen was discovered in 1792 and was proved essential to plants 80 years later; magnesium and boron were discovered as late as 1808 and were proved essential to plants approximately 100 years later. During the nineteenth century, eight of the elements were demonstrated to be essential to plants, and eight have been so proved in the twentieth century. (See Table 14.1.)

I. ELEMENTS ESSENTIAL FOR PLANTS AND ANIMALS

There are at present 16 elements which are known to be essential for the growth and reproduction of higher plants. These elements are : Carbon,

TABLE 14.1

THE 16 ELEMENTS ESSENTIAL FOR PLANTS: WHEN AND BY WHOM THEY WERE DISCOVERED, AND WHEN AND BY WHOM THEY WERE PROVED ESSENTIAL FOR PLANTS

Essential Element for Plants	Discovered by	Year Discovered	Proved Essential to Plants by	Year Proved Essential
Nitrogen	Lavoisier	1792	Rutherford	1872
Oxygen	Joseph Priestley	1774	De Saussure	1804
Iron	*	*	Gris	1844
Calcium	Davy	1807	Salm-Horstmar	1856
Carbon	*	*	Sachs	1882
Hydrogen	Cavendish	1766	Sachs	1882
Potassium	Davy	1807	Schimper	1890
Manganese	Scheele	1774	Bertrand	1897
Phosphorus	Brand	1669	Posternak	1903
Magnesium	Davy	1808	Willstatter	1906
Boron	Gay Lussac and Thenard	1808	Agulhon	1910
Sulphur	*		Peterson	1911
Copper	*	*	Brenchley	1914
Zinc	*	*	Maze	1915
Molybdenum	Hzelm	1782	Arnon and Stout	1939
Chlorine	Scheele	1774	Broyer, et. al.	1954

* Element has been known since ancient times.

hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, iron, sulphur, boron, manganese, copper, zinc, molybdenum and chlorine. Besides these sixteen elements, cobalt, vanadium, and sodium have been proved essential for blue-green algae. Jacob and Uexkull have listed cobalt and sodium as essential for plant growth. Stiles reports the essentiality of vanadium, sodium, silicon, aluminium, and gallium for certain species of plants. As more refined techniques are developed, future work will possibly enlarge the list of essential elements.

Since livestock are mostly forage-eating animals, it is of vital concern to know whether the elements essential for plants are also essential

for animals. Elements known to be essential for animals are: Carbon, hydrogen, oxygen, phosphorus, potassium, nitrogen, sulphur, calcium, iron, magnesium, copper, zinc, chlorine, sodium, iodine, manganese, and cobalt.

Among the elements essential for plants, boron and molybdenum are not essential for animals; but there is recent evidence indicating the possibility of molybdenum being essential for animals. Animals, however, need sodium, cobalt, and iodine which are not required by plants.

The essentiality of an element is proved by the following criteria. When:

(a) Rigid exclusion of the element from the nutrient medium completely inhibits or drastically reduces the growth. Whatever growth does occur may be attributed to traces of the element which the most careful control fails to exclude.

(b) The acute deficiency of the element produces certain well defined symptoms of disease which are not produced by the deficiency of any other element.

(c) Deficiency disease can be cured by the supply of the particular element before the living system has been damaged beyond repairs.

Briefly the element may be considered essential if its exclusion prevents the plant (or animal) from completing its life cycle.

Among the nutrients considered essential for plants, certain nutrients like boron, manganese, copper, zinc, and molybdenum are required in small or trace amounts. These nutrients are therefore called micronutrients. The micronutrients have a very high efficiency value, i.e., very small quantities are sufficient to produce optimum effects. However, slight deficiency or slight excess can cause severe damage to plants. The range from deficiency condition to that of excess is extremely short in the case of these nutrients, thus, great care needs to be exercised in the use of micronutrients.

2. THE FORMS OF NUTRIENT UPTAKE

Plants take carbon, hydrogen, and oxygen chiefly from air and water. Other nutrients are taken from the soil mostly in the form of ions. The 16 essential elements move into the plant primarily in the following forms:

C CO_2 (mostly through leaves)

H H^+, HOH

O O^{++}, OH^-, CO_3^{--}, SO_4^{--}, CO_2 (mostly through leaves) *

* Research in the United States of America has shown that from water only the hydrogen is utilised by green plants; oxygen in water is liberated as a gas.

P	$H_2PO_4^-$
K	K^+
N	NH_4^+, NO_3
S	SO_4^{--}
Ca	Ca^{++}
Fe	Fe^{++}, Fe^{+++}
Mg	Mg^{++}
B	BO_3^{--}
Mn	Mn^{++}
Cu	Cu^{++}
Zn	Zn^{++}
Mo	MoO_4^{--}
Cl	Cl^-

Russian workers have reported that although plants take most of their carbon through their leaves, appreciable quantities of carbon from dissolved CO_2 in water is also absorbed through the roots. These studies were made possible by radioactive carbon, C^{14}. They report increased photosynthetic activity in plants grown on soils which provide increased CO_2 due to decomposition of organic matter. These workers visualize the use of carbonic fertilisers along with N, P, and K fertilisers.

3. THE MECHANISM OF NUTRIENT UPTAKE

Plants obtain nutrients from these four devices :

1. Through the leaves
2. From the soil solution
3. From exchangeable ions on the surface of clay and humus particles.
4. From readily decomposable minerals.

All crop plants feed mostly by root uptake of nutrients from the soil. According to available knowledge, carbon is taken chiefly as carbondioxide through the stomata of leaves. Water also is absorbed through the stomata, but the relative amount is small as compared with that which enters the roots. Many nutrients are capable of being absorbed by the leaves of plants. (This will be discussed in the following section.)

Most of the nutrients enter the plant roots as ions, either anions or cations. The source of these required ions is the soil. A fertile soil provides ample amounts of them in reasonable balance. To promote growth, the nutrient ions must pass into the plant. Thus an intricate and

important process lies between the supply of nutrients by soil and the concentration of nutrient ions needed by the plant. The process of ion absorption functions optimally in a fertile, moist, and well aerated soil.

A great deal of experimental work has been done on ion absorption, but

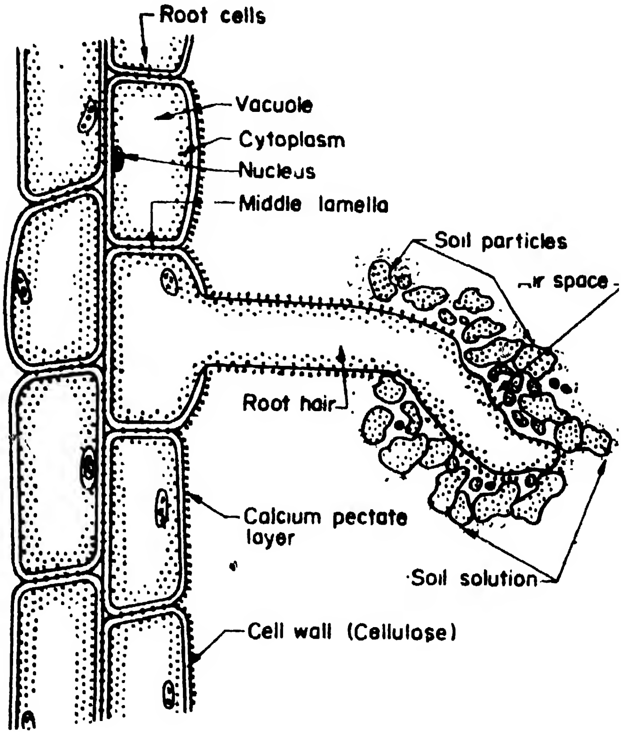

Fig. 14.1 Most nutrients enter the plant from the soil solution through the calcium pectate layer in the cell wall of the root hairs, and then into the cytoplasm. Nutrients move from the root hair to other cells in a similar manner. Nutrients are then released from soil and humus particles to the soil solution to maintain an equilibrium. (Redrawn from *1957 Yearbook of Agriculture*, United States Department of Agriculture.)

the mechanism of uptake is still not very clear. The "carrier" hypothesis is widely accepted and is supported by many observations. Hanson has given brief details of this process which is as follows.

The first step in the ion uptake by growing plants is the adsorption of ions by calcium pectate colloids of the cell wall and then by the cytoplasm. The process is most apparent with the positively charged ions (cations), as the plant colloids are predominant with negative charges. Figures 14.1

and 14.2 are shown to illustrate cationic exchange between a root and clay and humus colloids, and between the root and the soil solution, respectively. The source of additional cations is shown from a slowly decomposing limestone fragment which releases calcium ions (Ca^{++}) to the soil solution and to clay and humus particles. The root hair releases two hydrogen ions

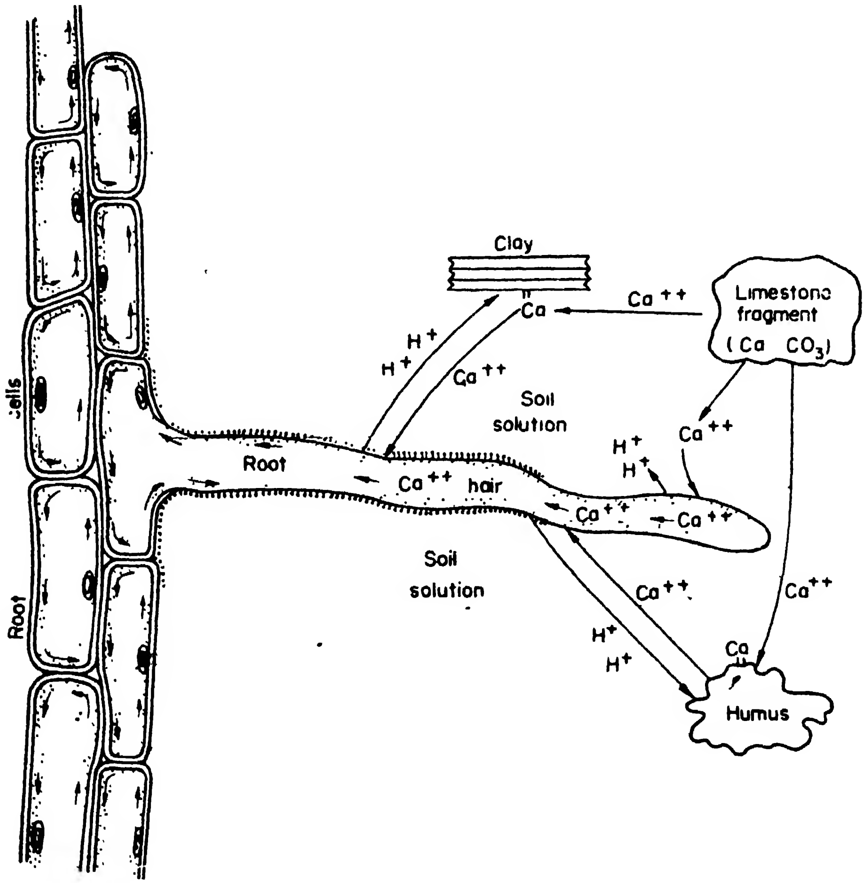

Fig. 14.2 A diagrammatic scheme for showing how a root hair takes in nutrients from the soil solution. These nutrients *originally* came from readily decomposable rocks and minerals (limestone, shown here) or *secondarily* from the surfaces of clay and humus particles. (Arrows inside cells indicate "streaming" of protoplasm).

for each calcium ion it absorbs from either the soil solution, a clay particle, or a humus particle.

The second phase of ion absorption is transfer of the adsorbed ions through the cytoplasm and into the cell sap. This transfer process cannot

take place without metabolic energy from respiration. The sap concentration of a cation such as potassium may be only one hundredth that of the soil solution. The absorption of ions against the osmotic gradient can be attained only by the use of energy in ion transport work. It has been proved that when root respiration is limited by reason of low temperature, poor soil aeration, or low sugar supply from the leaves, ion absorption is also reduced. Thus, respiration furnishes the energy for absorption.

According to the "carrier" hypothesis, the cytoplasm contains certain "carriers" that adsorb ions at the outer membrane and are responsible for transporting the ions to the cell vacuole, which is considered to be the storehouse of the cell. The cytoplasm appears to be able to withdraw substances from the vacuole as needed. These carriers are presumably proteinaceous. The "streaming" (constant movement) of the cytoplasm is another process requiring energy, and transports the ion-laden carriers throughout the cytoplasm.

The nutrient cations such as Ca^{++}, K^{+}, Mg^{++}, and NH_4^{+} are held on clay colloids and on humus in an exchangeable and available form for use by plants. This is not the case with anions. Nitrates, sulphates, borates, and molybdates, are nutrient anions and therefore are not held by clay and humus by the same mechanism. Phosphates anions are held by soil colloids to a small extent, as compared to cations. Available anions exist either in the soil solution or in some chemical compound in equilibrium with the soil solution. Phosphorus, sulphur, boron, and molybdenum are a part of the crystal structure of such minerals as apatite, tourmaline, and pyrite. But the nutrient elements in these minerals are so slowly soluble as to supply too few anions for normal plant nutrition, even though the minerals are finely ground.

It is soil organic matter that serves as the principal store house for the anions. Through the decomposition of organic matter by bacteria, fungi, and actinomycetes and subsequent oxidation, the anions are made available to growing plants through the soil solution.

Almost all nitrogen is held in the soil in the organic matter. Organic phosphorus may account for from 10 to 50 per cent of the total soil phosphorus. Up to 80 per cent of soil sulphur has been reported to be held in the organic form. Boron and molybdenum reserves seem to be stored both in organic matter and in clay.

The ion absorption process is most efficient under the following conditions when :

1. The soil has a high concentration of nutrient ions.
2. The soil is well aerated, allowing oxygen to diffuse readily into the soil and carbondioxide to diffuse out.
3. The soil is sufficiently moist to permit ions in solution to contact large areas of root surfaces. Moisture is the medium for transport.
4. The leaves are exposed to adequate light.

The leaves synthesize sugars which, when transported to the roots, provide energy for root respiration. When the plant population in a field is excessive, many leaves remain shaded, the root sugar content drops, and there is a consequent decrease in ion absorption and growth.

There is good evidence to support the theory that anions are taken into the plant only from the soil solution. But the amounts of anions in the solution at any one time are not enough to supply the plant for the entire growing season. The only logical answer is that as anions in the soil solution are taken up by the plant, other anions are released to the soil solution by organic decomposition or from slowly soluble compounds. It is also generally agreed that, as plant roots take in nutrient anions, the roots release OH^- or HCO^-_3 ions in exchange.

For maximum production, crop plants usually require greater amounts of nutrients than the soil solution contains at any one time. As plants remove nutrient ions from the soil solution, the soil solution is being replenished by cationic exchange, from the slow decomposition of soil minerals, and from the more rapid decomposition of soil organic matter. It is seldom, however, that the rate of renewal for all essential elements is fast enough to achieve maximum crop production ; for this reason, the use of fertilisers is needed.

4. FOLIAR NUTRITION OF PLANTS

It has been known for many years that plants are able to absorb essential elements through their leaves. The absorption takes place through the stomata of the leaves and also through the leaf cuticle. Movement of elements is usually faster through the stomata, but the total absorption may be as great through the cuticle. Both woody and herbaceous plants are also capable of absorbing nutrients through the surface of their stems.

The following elements have been successfully used to supply nutrients for plant growth by applying them as foliar sprays to the leaves :

PRIMARY NUTRIENTS	SECONDARY NUTRIENTS	MICRONUTRIENTS
Nitrogen	Calcium	Iron
Phosphorus	Magnesium	Zinc
Potassium	Sulphur	Boron
		Copper
		Manganese
		Molybdenum

Nitrogen fertiliser compounds have been used for several years as foliar sprays. Sodium nitrate, ammonium sulphate, potassium nitrate, and urea have all been used experimentally, but only urea gives satisfactory results. The other nitrogen fertilisers cause the burning of leaves, due partly to the high osmotic concentration of the spray solution. Collings in 1955 reported that urea as such may be utilized to a limited extent by some plants.

Urea has been successfully sprayed on apple, orange, tea, mulberry, tomato, rice, wheat, barley, rye grass, pasture grasses, sweet potato, cabbage, and spinach. Amounts up to 15 pounds of urea per acre at one spraying have been used with beneficial results on apple trees. The usual concentration for apple trees is five pounds of urea per 100 gallons of water. For crops like rice, wheat, barley, rye and pasture grass a concentration of 15 pounds of urea in 100 gallons has been successfully tried in Japan. For spinach and cabbage 5-10 lbs. urea in 100 gallons of water is used. An increase of 10 to 50 per cent in the protein content of the grain has been obtained for food crops, and a 10 to 30 per cent increase in the yield of various other crops. Experiments at the Indian Agricultural Research Institute, New Delhi, have also proved the beneficial effects of urea as a foliar spray on wheat at 6 lbs. of urea in 100 gallons of water. The increase in yield and protein content of grain was observed. Experiments on jute at the Indian Jute Research Institute, Barackpore, West Bengal, have shown that the cheapest method to achieve large increases in acre yield of jute is to spray the leaves of plants with an aqueous solution of urea four times with a concentration of 10 pounds in 100 gallons of water.

The application of urea fertiliser to leaves of plants in general has given approximately equal response to that of fertiliser applied to the soil. The uptake of urea is faster when it is sprayed on the leaves. The response to spray application may be expected within 24-48 hours after application.

Phosphorus is capable of being utilised by the plant when it is sprayed on the leaves. Although the practice is not common, there are good reasons for predicting that there may be an increase in the foliar application of phosphorus.

One reason is that in most soils only a small percentage of phosphorus fertilisers is recovered by the plant ; whereas, when phosphorus is sprayed on the leaves, nearly all of it is absorbed. In one experiment in U.S.A. approximately three pounds of P_2O_5 sprayed on tomato leaves gave a *greater early growth* than did 135 pounds of P_2O_5 applied to the soil. The *yield* of tomatoes, however, was 12 per cent greater when the 135 pounds of P_2O_5 was applied to the soil than when 3 pounds of P_2O_5 was sprayed on the leaves.

Potassium applications as foliar sprays have been made, using potassium sulphate fertiliser. Some leaf injury resulted, and the conclusion was reached that soil applications are far more satisfactory.

Magnesium is now commonly applied to plant foliage as solutions of magnesium sulphate (Epsom salt). One reason for the popularity of the practice is that soil applications of magnesium commonly take three years to correct magnesium deficiency symptoms of such perennials as apple trees, whereas foliar sprays are effective within a few days after application.

A foliar application of a 2 per cent solution of magnesium sulphate to tomatoes, oranges, and apples has relieved magnesium deficiency and has increased crop yields.

Calcium is seldom applied as a foliar spray because it can be efficiently applied to the soil. If calcium carbonate is too slow in reaction, then calcium oxide or calcium hydroxide can be applied to the soil. But there is no good reason why calcium cannot be applied as a foliar spray.

Sulphur sprayed on leaves is readily absorbed by the plants. This fact was demonstrated, however, in connection with the study of the influence of certain sulphur sprays when used as a fungicide. Although there have been no reports of a sulphur deficiency being relieved by sulphur sprays, the practice may become established because it is physiologically sound.

Iron has been sprayed on foliage since about 1916 to relieve chlorosis. The first of such research work was carried out with chlorotic pineapples growing on highly alkaline soils in Hawaii. Periodic sprays of five per cent ferrous sulphate are now common practice on Hawaiian pineapple plantations. The biggest obstacle to this practice is the fact that, even though the iron moves readily into the leaves, it is translocated very slowly. As a result, after spraying with ferrous sulphate chlorotic spots may still be in evidence in places which did not receive some of the iron spray.

On alkaline soils where iron chlorosis is common, applications of iron compounds to the soil have not been very successful because the iron is soon rendered insoluble.

A chlorotic field of grain sorghum on calcareous soil in Tulare county, California, U.S.A., was sprayed with 40 gallons per acre of a 3 per cent ferrous sulphate solution about one week before heading, at a cost for materials of 50 cents (equivalent to Rs. 2.50) per acre. The yield of grain sorghum was increased from 540 pounds of grain on the untreated plot to 1,740 pounds on the treated plot. Soil applications of more than 3000 pounds per acre of ferrous sulphate were required to accomplish similar increases in yields.*

Zinc is often sprayed on the the leaves of apple and pear trees to relieve "leaf rosetting", a symptom of zinc deficiency. Approximately 25 pounds of zinc sulphate in 100 gallons of water (roughly a three per cent solution) applied to apple trees just before the buds open has corrected zinc deficiency. Zinc sulfide, zinc oxide, and zinc carbonate have all been successfully used as sprays. Driving galvanized (zinc-coated) nails in trees also relieves zinc deficiency.

Boron as boric acid or borax (sodium tetraborate) used as a foliar spray has proved to be a successful method of application. Internal cork of apples has been controlled by spraying the foliage with eight pounds of borax in 100 gallons of water. As little as two pounds of borax per 100 gallons of water has checked "cracked stem" of celery. Boron is also satisfactorily applied to the soil, either alone or in mixed fertilisers.

Copper deficiency has been controlled by spraying the leaves with a mixture of 8 pounds of copper sulphate plus 8 pounds of calcium hydroxide in 100 gallons of water. Without the calcium hydroxide, the copper sulphate injures the foliage.

Molybdenum deficiency has been reported from Florida U.S.A., on citrus. It is found on soils which are very acid, naturally poor in molybdenum, and strongly leached. Treatment consists in foliar spraying with ammonium or sodium molybdate at a rate of 3 to 12 gm. per tree in 40 litres (9 gallons) of water. The results are apparent after 3 or 4 weeks, after the absorbed molybdenum migrates into the leaves. Somewhat like iron, however, molybdenum does not seem to be readily translocated within the plant. Spraying only the lower half of a citrus tree that showed molybdenum deficiency did not cure the deficiency symptoms on the upper half of the tree.

* Krantz, B. A., A. L. Brown, B. B. Fischer, W. E. Pendery and V. W. Brown. *Foliage Sprays Correct Iron Chlorosis in Grain Sorghum.* California Agriculture, (16) 5 : 5, 6. 1962.

One difficulty in using foliar sprays to supply essential elements to crops is that translocation of the applied element may not be rapid enough for increasing crop yields. With some plants this problem is more difficult than with others. The relative mobility of essential elements in bean plant when applied as a foliar spray is given in Table 14.2.

TABLE 14.2
CLASSIFICATION OF NUTRIENTS AS TO THEIR RELATIVE MOBILITY IN THE BEAN PLANT FOLLOWING FOLIAR ABSORPTION*

Mobile	Partially mobile	Immobile
Potassium	Zinc	Magnesium
Phosphorus	Copper	Calcium
Chlorine	Manganese	
Sulphur	Molybdenum	

Listed in order of decreasing mobility.

* *Source* Bukovac, M.J. and S.H. Wittwer, *Absorption and Distribution of Foliar Applied Mineral Nutrients as Determined with Radioisotopes.* As reported in : Reuther, Walter, Editor, *Plant Analysis and Fertilizer Problems.* Pub. No. 8, American Institute of Biological Science, Washington, D.C. 1961.

Data for magnesium and calcium suggest an initially rapid absorption by plant foliage, which decreases sharply after the first few hours. Salts of divalent cations may be applied to plant foliage at considerably higher concentrations than those of other salts.

5. PHYSIOLOGICAL ROLE OF ESSENTIAL NUTRIENTS

(Common deficiency symptoms in maize are shown on the Frontispiece.)

Nitrogen: Nitrogen in the form of proteins is present in the protoplasm of every cell. In addition, nitrogen is present in many other compounds which are of great physiological importance in metabolism, such as chlorophyll, nucleotides, phosphatides, and alkaloids ; as well as in many enzymes, hormones, and vitamins. Nitrogen deficiency, therefore, exerts a marked effect on crop yield.

Nitrogen makes plants dark green and more succulent ; it also makes larger cells with thinner cell walls. In addition, nitrogen increases the proportion of water and decreases the percentage of calcium in plant tissues. Nitrogen promotes vegetative growth and encourages the formation of good quality foliage by promoting the production of carbohydrates, and encouraging succulence.

Recent research in Arkansas (U.S.A.) has demonstrated that many crops when fertilised with nitrogen have an increased ability to absorb not only more nitrogen but also more phosphorus, potassium, and calcium. Nitrogen

fertilisation increases the cation exchange capacity of plant roots and thus makes them more efficient in absorbing other nutrient ions.

There are nearly 12 pounds of nitrogen above every square foot of the surface of the earth, yet nitrogen is one of the most critical elements for plant growth. The reason is that plants cannot utilize nitrogen as a gas ; it must first be combined into stable form.

Plants absorb nitrogen either as the ammonium or the nitrate ion. The ammonium ions can be held in an exchangeable and available form on the surfaces of clay crystals and humus but bacteria soon transfer the ammonium to nitrates, which are readily leachable. There is no good storehouse for available forms of nitrogen. The only store house of any kind for nitrogen is soil organic matter.

Soil organic matter is approximately five per cent nitrogen, it therefore follows that :

$$\% \text{ N X } 20 = \% \text{ organic matter}$$

Phosphorus : Phosphorus is found in every living cell and is essential in both plant and animal nutrition. It occupies a key position in metabolism. Carbohydrate metabolism proceeds normally only when the organic compounds are esterified with phosphoric acid. Phosphorus plays an important role in energy transformations and participates in fat and protein metabolism. It is an essential constituent of many vital compounds like nucleotides, lecithins and most enzymes. The effects on plant growth are given as follows :

1. The most obvious effect of phosphorus is on the root system of plants. It promotes the formation of lateral and fibrous roots which increases the absorbing surface for nutrients. Phosphorus-starved plants have a stunted and poorly developed root system which decreases their feeding zone.
2. Phosphorus increases the number of tillers in cereals and thus the number of shoots is increased which finally bear ears and grain.
3. Phosphorus hastens the ripening of plants. In the presence of sufficient available phosphorus, seed formation begins sooner and crops mature several days earlier than when phosphorus is deficient. It is essential for seed formation.
4. Fodder crops grown on phosphorus deficient soils contain reduced amounts of this element and thus are of inferior value when fed to livestock.
5. Phosphorus gives strength to the straw and helps to prevent lodging.

6. Phosphorus increases the ratio of grain to straw in cereals and thus increases the yield of grain.
7. Phosphorus increases disease-resistance in plants, presumably due to normal cell development and resulting vigorous growth.
8. Leguminous crops grown under phosphate deficiency conditions may suffer from nitrogen deficiency as well, since the nodule bacteria function normally only when plants are supplied with adequate phosphorus.

One of the difficult problems facing the plant nutrition worker is to convince the farmer and the public that a deficiency of phosphorus quite often does not become apparent through a decrease in plant yields but may be apparent through the decrease in phosphorus content of the plant, ultimately causing malnutrition of the animals and men feeding on them.

The phosphorus nutrition is therefore critical. The total supply of phosphorus in most soils is usually low, and its relative availability is also low. Plants absorb phosphorus from the soil solution mostly in the from of $H_2PO_4^-$ ions.

The total phosphorus in an average arable soil is approximately 0.1 per cent, only a minute fraction of which is available to the plant at one particular time. Under ideal conditions, as plants take in $H_2PO_4^-$ ions from the soil solution, other ions replace them from slowly soluble compounds in the soil. The colloids hold exchangeable phosphate anions only to a small extent.

Phosphorus availability is low in strongly acid soils because of the formation of iron and aluminium phosphates, from which phosphorus is very slowly available. In calcareous soils, tricalcium phosphate $Ca_3(PO_4)_2$ forms readily, to reduce the availability of soil phosphorus.

Potassium: Potassium is a vitally important mineral element which the plant requires in the largest quantity. It occurs chiefly in a state of solution of inorganic and organic salts. Until a few years ago it was thought that all potassium in the plant was in a mobile form. Radioactive potassium techniques have demonstrated, however, that part of the plant potassium is fixed in plant proteins.

The effects of potassium on plants are as follows :

1. Potassium increases the efficiency of the leaf in manufacturing sugars and starch. This fact explains the need of potato and sugarbeet for large amounts of potassium. The size and weight of cereal grains is considerably increased by adequate potassium. The action of potassium is said to be complementary

to that of nitrogen; the latter increases the size of the leaf and the former its efficiency.

2. Potassium helps to maintain cell permeability, aids in the translocation of carbohydrates, and keeps iron more mobile in the plant.
3. Potassium increases the plant's resistance to disease. It is not known whether potassium enables the plant to withstand attacks of organisms or whether the organisms become established more easily in potassium-deficient tissue than in normal tissue.
4. Potassium is an activator of a number of amino acid-activating enzymes and it markedly enhances the amino acid incorporation and synthesis of proteins.
5. Potassium, being highly mobile, encourages normal cell division in young meristematic tissues.
6. The potassium ion is in part responsible for the maintenance of proper turgor of plant cells. Potassium is thought to affect the colloidal cytoplasm and helps to regulate the degree of swelling and water economy of cells. This property probably explains the resistance of plants to dehydrating effects of frost and drought. Thus, it imparts winter-hardiness.
7. Potassium helps to produce strong stiff straw in cereals, specially rice and wheat; thus, it reduces lodging.
8. Besides being an activator for enzymes involved in protein synthesis, potassium is an activator for several enzymes involved in carbohydrate and nucleic acid metabolism, e.g., pyruvic kinase, fructokinase, phosphofructo kinase (in carbodhydrate metabolism) and formylase, a polynucleotide phosphorylase (in nucleic acid metabolism).

In potassium deficiency conditions, the net synthesis of complex carbohydrates, proteins, or nucleic acids is reduced and synthesis of simple sugars, amino acids, and nucleotides is increased. Recent research indicates that probably the process of synthesis and hydrolysis are both affected by potassium.

The amount of total potassium in all soils is sufficient to last for ever, yet the money spent for potassium fertilisers is constantly on the increase. An explanation of this apparent contradiction lies in the fact that most of the potassium is part of the silicates which are only very slowly decomposed. Soils may contain one to two per cent total potassium, only one fiftieth to one hundredth of which at any one time is in a readily available form (exchangeable). However, during the growing season, approximately half of the potassium absorbed by the plant may come from the exchangeable

form and the other half from relatively insoluble minerals and nonexchangeable (fixed) potassium.

Calcium : (1) Calcium tends to make the plants more selective in their absorption ; and since it is a constituent of the cell wall, it therefore helps in increasing stiffness of straw.

(2) Rapidly growing root tips are specially high in calcium, indicating that calcium is needed in large quantities for cell division. It promotes early root development.

(3) Calcium provides a basic material for neutralization of organic acids. In this manner it acts as a detoxifying agent.

(4) Calcium encourages seed production.

(5) Increasing Ca : K ratio in soil solution depresses the uptake of potassium. One of the harmful effects of overliming may result from decreased K uptake. Where potassium is in excess, calcium prevents luxury consumption of potassium by the plant and thus avoids wastage.

(6) In calcium deficiency conditions, soluble nucleotides are increased and net synthesis of nucleic acid is decreased.

Calcium in soils is usually abundant except in acid soils, which occur in humid areas due to excessive leaching. Most of the reserve calcium is in the form of calcium carbonate (limestone). When compared with most potassium minerals, calcium-bearing minerals are usually much more soluble. As a consequence, there is nearly always more exchangeable calcium on the clay/humus colloids than there is of potassium.

Magnesium : Chlorophyll contains one atom of magnesium in each molecule ; therefore, there could be no green plants without magnesium. Magnesium deficiency may help to cause chlorophyll deficiency-chlorosis. (See Figure 14.3.)

Magnesium aids in the uptake of phosphorus. Magnesium plays an essential role in many enzymatic reactions, chiefly phosphorylating reactions, i.e., those involved in the formation of phosphoric acid esters of organic compounds. Thus, it increases the efficiency of phosphorus absorption. Magnesium also helps in the translocation of carbohydrates, and regulates the uptake of other nutrients, presumably, by its help in the formation of phosphorylated compounds.

Reserve magnesium occurs mostly in dolomitic limestone, a rock which consists of a mixture of calcium and magnesium carbonates. Dolomitic limestone is not so readily decomposed as is calcic limestone ; for that reason, the amount of exchangeable magnesium is usually less than that of exchangeable calcium.

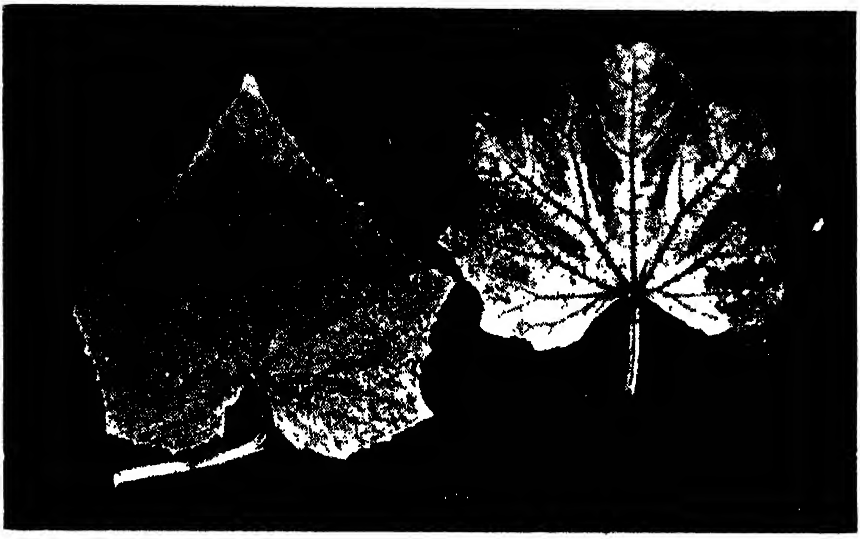

Fig. 14.3 Cucumber needs magnesium Left : 160 pounds per acre of MgO, applied as Sul-PO-Mag. Right : No magnesium Note chlorotic condition (*Courtesy Allan B. Prince, New Jersey Agricultural Experiment Station, United States of America*).

Sulphur: Sulphur is a constituent of enzymes and other proteins. Many of the enzymatic reactions take place due to the presence of sulphydryl group of enzymes. Sulphur is also present in coenzymes such as coenzyme A, thiamine pyrophosphate, and biotin. These coenzymes participate in several metabolic reactions involving the metabolism of carbohydrates, fats, and proteins. Sulphur is known to stimulate root growth, seed formation, and nodule formation. It also helps in chlorophyll formation. Sulphur is found in small amounts in the soil, averaging perhaps 0.15 per cent in a typical soil. A large part of the sulphur which plants use comes from decomposing organic matter or from fertilisers.

Micronutrients : Iron, manganese, zinc, copper, boron, molybdenum, and chlorine are listed as micronutrients because they are used by plants in such small amounts. These elements may limit plant growth either because there may not be a sufficient amount of them in the soil or, as is more often the case, because some condition in the soil reduces their availability.

All of the micronutrients except molybdenum and chlorine are more available in an acid soil ; molybdenum solubility increases with liming.

Iron is not a constituent of chlorophyll, but it is essential for its formation. It is involved in several oxidation-reduction reactions in plants and is therefore essential for synthesis of proteins and several metabolic reactions.

Manganese acts as a catalyst in oxidation-reduction reactions in the plants, especially in connection with iron and nitrogen metabolism. Manganese is an activator of many enzymes, e.g., phosphoglucomutase, choline esterase, and β-ketodecarboxylases. It is also related to chlorophyll synthesis, since manganese deficiency causes chlorosis (See Figure 14.4.)

Fig. 14.4 Manganese deficiency causes chlorosis **Left :** Normal cotton leaf **Centre :** Incipient manganese deficiency on cotton leaf **Right :** Severe manganese deficiency on cotton leaf. (*Source* Fertilizer Salesman's Handbook, National Plant Food Institute, Washington D.C)

Manganese deficiency usually results from decreased availability. Available manganese is low in soils with alkaline reaction and with high calcium carbonate.

Recent studies in Madhya Pradesh, India, have shown that some areas in the state may have less than 3 ppm available manganese (water soluble+exchangeable manganese).

Zinc is a constituent of a number of enzymes, e.g., carbonic anhydrase, alcohol dehydrogenase, and various peptidases. It is therefore essential for a number of enzymic reactions. It also helps in the formation of growth hormones (See Figure 14.5.)

Copper activates a group of oxidising enzymes and is a constituent of certain proteins. It is involved in ascorbic oxidase, butyryl CoA dehydrogenase (involved in fat metabolism), tyrosinase, and other enzymes.

It is known to act as an "electron carrier" in enzymes which bring about oxidation-reduction, and regulates respiratory activity in plants.

Boron enzymatic role has yet been discovered. It is however involved in the uptake of calcium and its efficient use by plants. The lack of adequate boron tends to increase the loss of phosphorus from plant roots. Boron also seems to act as a regulator of the potassium/calcium ratio, is intimately related to the absorption of nitrogen, and is necessary in cell division. Protein synthesis is broken down if boron is deficient. Boron is required in extremely small amounts, in the range of 0.01 to 1.0 ppm.

Fig. 14.5 Typical zinc deficiency of maize is characterized by : (1) Purpling around the leaf sheaves, similar to P deficiency. (2) Death in older leaves on edges, similar to K deficiency. (3) Yellowing of all leaves, similar to N deficiency. (*Courtesy* : W. L. Parks, Tenn. Agr. Exp. Sta. U.S.A.)

Molybdenum is intimately related to nitrogen metabolism of plants. It is part of the nitrate reductase system which helps to utilize nitrate for nitrogen requirements prior to amino acid synthesis. It is also essential for nitrogen fixing organisms, both symbiotic and nonsymbiotic.

Chlorine need for plant development has been established for sugarbeets, carrots, cabbage, lettuce, barley, wheat, cotton, and clovers. Of all the plants examined, lettuce is most susceptible to injury resulting from chlorine deficiency. The exact role in plant nutrition is not definitely established. Chlorine is thought to be essential for the photosynthetic process.

Work in India and Pakistan has shown that wheat grown in soils with a very low soluble salt content have responded to small applications of sodium chloride.

6. SOIL PHYSICAL CONDITIONS AND PLANT NUTRITION

Adequate amounts of nutrients for desirable plant growth may be "available" according to any chemical test but actually deficient because

Fig. 14.6 Crop plants cannot be expected to produce maximum yields in this soil, even when adequately fertilised, because of the cloddy surface. (Near Sholapur, Maharashtra State, India).

of soil physical conditions. Tillage pans, cloddy surface soils, surface crusts, or lack of soil aggregation may reduce nutrient availability for one of these reasons (See Figures 14.6 and 14.7.)

1. By physically restricting root elongation, especially deep root penetration, the volume of soil in contact with plant roots and the total nutrients absorbed by the roots will therefore be limited.

2. By restricting the exchange of oxygen and carbondioxide in the soil, the ability of plant roots to translocate nutrients to the leaves is restricted.

3. By retarding the growth of nitrifying bacteria, the soil nitrogen may remain as unavailable protein instead of breaking down to release available ammonium or nitrate ions.

4. By reducing water infiltration, water may become the first limiting factor in plant growth even though all nutrients are present in adequate amounts.

Well aerated soils, by providing more oxygen, would stimulate respiratory activity and encourage a larger uptake of nutrients by roots. Significant differences in nutrient uptake by plants grown under different tillage practices have been reported. Potassium and nitrogen are the

nutrients most affected. The influence of aeration on growth and nutrient absorption studied by Lawton showed that the order of reduction in nutrient absorption by corn due to restricted aeration was K > Ca > Mg > N > P. The increase in nutrient absorption was associated with forced aeration.

Fig. 14.7 This tillage pan, starting at a depth of approximately 6 inches, has forced the cotton roots to grow horizontally, thus restricting the volume of soil from which the plant roots are able to obtain plant nutrients. (Near Olney, U.S.A.) (*Courtesy* Caterpillar Tractor Co)

The lack of balance in air and water within the soil brings about a number of effects, e.g., water-logging due to poor drainage brings about reduction of sulphate and a decrease in availability of sulphur. Recent experiments at the Indian Agricultural Research Institute in laboratory and pot experiments have shown the superiority of ammonium sulphate to urea in rice paddy soils. This has been explained on the basis of decreased availability of sulphur under waterlogged condition. Ammonium sulphate by providing available sulphur helped to give larger response to ammonium sulphate.

Water-logging brings about a number of other changes in microbial activity. Nitrification is decreased and denitrification is stimulated. Poor aeration would account for a decreased uptake of nutrients by most crop plants except rice, which appears to have a distinct mechanism of root absorption and root metabolism. Rice appears to have an internal conducting system in its stems and roots for air movement.

The ability of plants to absorb water and nutrients depends on permeability of root surfaces which is in turn are influenced by the metabolic activity of the roots. The metabolic activity is increased by supplying oxygen to the roots and removing carbondioxide. Higher soil temperature in the root zone in winter months tends to increase growth primarily through higher uptake of nutrients. This probably would explain

the beneficial effect of mulches on plant growth in winter. The effect of temperature on the uptake of nutrients by excised barley roots is illustrated in Table 14.3.

TABLE 14.3
ACCUMULATION RATIOS FOR POTASSIUM, NITRATE, AND HALIDE IN EXCISED BARLEY ROOT SYSTEMS, AS INFLUENCED BY TEMPERATURE

Temperature	Accumulation ratio		
°C	K	NO_3	Halide
6	3.6	0.6	1.2
12	5.1	1.3	1.9
18	8.7	3.1	3.1
24	12.3	5.2	7.2
30	15.1	7.1	10.1

Accumulation ratio is the concentration in the barley root sap divided by the concentration in the external solution.

Source: Hoagland, D.R. and T.C. Broyer, *General Nature of the Process of Salt Accumulation by Roots, with Description of Experimental Methods.* Plant Physiol. 11 : 471-507, 1936.

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CHAPTER FIFTEEN

FERTILISERS AND THEIR CHARACTERISTICS

> " *Without manure, rice plants grow but do not bear a crop.*"
>
> PARASARA, CIRCA, 1300 B.C.

The interest in the production and use of chemical fertilisers, natural and synthetic, started since the time Liebig in his "Law of Restitution" pointed out that for the maintenance of soil fertility, the replacement of the nutrients removed from the soil by the crops was necessary. Plants require sixteen elements for their growth. These are carbon, hydrogen oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, boron, copper, manganese, zinc, molybdenum and chlorine. It is likely that sodium and cobalt may be added to the list of essential nutrients in the near future.

The first three elements are obtained by the plant from air or water. Nitrogen, phosphorus and potassium are required by the plant in large amounts and are therefore designated major nutrients or primary nutrients ; while calcium, magnesium and sulphur are secondary nutrients. The requirement of these nutrients is generally supplied by the use of common nitrogen, phosphorus, and potassium fertilisers. For acid soils, the use of calcium and magnesium is necessary. Some soils also are very low in sulphur, but usually the amount of sulphur supplied in superphosphate is adequate for most crop needs.

Seven elements, iron, manganese, boron, molybdenum, copper, zinc and chlorine are required in trace amounts and hence, these are designated as micronutrients.

1. NITROGEN FERTILISERS

The primary deficiency of nitrogen in all Indian and in other Tropical Asian Countries demands top priority for the manufacture and supply of nitrogen fertilisers. The Planning Commission of India in their Five Year Plans has accorded a high priority for fertilisers, particularly nitrogen fertilisers. Following are the important nitrogen fertilisers in common use in Tropical Asia :

Ammoninm sulphate	20.6 % N
Ammonium sulphate nitrate	26.0 % N
Calcium ammonium nitrate	20.5 % N
Urea	45.0 % N
Ammonium chloride	25.0 % N

2. AMMONIUM SULPHATE [$(NH_4)_2$ SO_4] 20.6% N

Ammonium sulphate maintains first place among the sources of nitrogen fertilisers in Asia, providing 49 per cent of the total. In India too, ammonium sulphate is the chief fertiliser in use.

Ammonium sulphate is manufactured by two processes, namely (1) the gypsum process and (2) by absorption of ammonia in dilute sulphuric acid.

Gypsum process : This process is being employed in Sindri Fertiliser factory in Bihar State, India and in Alwaye (Kerala State, India). The chief raw materials are coal for the power generation, coke for generation of gas (ammonia and CO_2) and gypsum for reaction with ammonium carbonate to produce ammonium sulphate. The essential features of the process are :

1. The production of semi water gas which is a mixture of water gas ($CO+H_2$) and produces gas ($CO+N_2$). This is produced by passing alternate currents of steam and air over red hot coke.
2. The mixture of these gases is purified and mixed with steam and passed over a catalyst ; the carbon monoxide then becomes carbon dioxide,

$$CO + H_2O \rightarrow CO_2 + H_2$$

3. The mixture of hydrogen, nitrogen and carbon dioxide are compressed to a pressure of 5,200 lbs. per square inch, in stages. When the pressure is about 280 lbs. per square inch the gases are scrubbed with high pressure water to remove CO_2. Aga in when the pressure is about 1,800 lbs. per sq. inch, the gases are

washed by scrubbing with a solution of cuprous ammonium formate to remove carbon monoxide. The compressed mixture of nitrogen and hydrogen is then circulated and passed over a catalyst at a pressure of 5,200 lbs. per sq. inch and at about 510° C, when part of the mixture is converted to ammonia.

$$N_2 + 3H_2 \rightarrow 2NH_3$$

The ammonia formed is then condensed to a liquid and the unconverted gases returned to the process.

4. Ammonia is then brought into solution into which CO_2 is released. This results in the formation of ammonium carbonate.
5. Gypsum (calcium sulphate, $CaSO_4 \cdot 2\,H_2O$) is ground to a fine powder and is made to react with the solution of ammonium carbonate.

$$CaSO_4 + (NH_4)_2CO_3 \rightarrow CaCO_3 + (NH_4)_2SO_4$$

6. Ammonium sulphate being highly soluble in water, remains in solution and the calcium carbonate being insoluble remains in suspension. This suspension is subjected to filtration in vacuum filters. The filtrate containing ammonium sulphate is then concentrated, crystallized and the crystals are dried, cooled and put into storage or directly into jute bags.

Chalk ($CaCO_3$) obtained as a by-product in this process can be used for cement manufacture or for neutralizing acid soils. This by-product $CaCO_3$ contains small amounts of ammonium sulphate.

Ammonium sulphate manufactured by absorption of ammonia in sulphuric acid : Generally, ammonia for this process is obtained as a by-product from coke ovens. The coke oven gas, after it is freed of its tar in the coolers, is made to bubble through a saturator containing a bath of 4-5% free sulphuric acid. Here the ammonia reacts with sulphuric acid to form ammonium sulphate. The ammonium sulphate crystals are removed from the saturator by centrifugation.

During centrifuging, a hot water wash is given to remove traces of acid from the surface of crystals. The crystals are then dried and packed in gunny bags.

This process is used by steel factories and coal industries on a relatively small scale in India. Presently 83 per cent of ammonium sulphate in India is manufactured by the gypsum process, the rest as a by-product of the coal and steel industry.

Reaction with soil : Ammonium sulphate is a quick acting fertiliser with good storage qualities. On addition to the soil it reacts with soil colloids, thereby replacing bases, chiefly calcium, from the exchange complex.

$$Ca(Colloids) + (NH_4)S_2O_4 \rightarrow NH_4(Colloids) + CaSO_4$$

In humid areas the resulting calcium sulphate is soluble and is liable to be lost by leaching. The ammonium radical is then slowly released and is converted into nitrate by nitrifying bacteria. Nitrate also seeks a base. The resulting nitrate salt is soluble. Part of it is utilized by the plant and part lost in leaching as $Ca(NO_3)_2$. The extent of loss of calcium from soil would depend upon rainfall and soil permeability. On an average 109 lbs. of calcium carbonate are lost with the addition of 100 lbs. of ammonium sulphate. Thus the net effect of ammonium sulphate addition is to leave residual acidity. The danger of soil becoming acidic with the application of ammonium sulphate depends on the total quantity of fertiliser, lime status of the soil, and the rainfall.

Because of this acid-producing nature of ammonium sulphate, there is an apprehension among some cultivators that ammonium sulphate may not be a good fertiliser. The continuous use of ammonium sulphate on soils with low lime status will cause acidic conditions and can be met with by an adequate liming programme. Such acidic effect, however, is not produced in one year but after continuous use for many years. At Rothamsted, England, in soils with 4% lime, the use of ammonium sulphate for 80 years has not affected crop growth. It is estimated that soils with 10% lime will not be acidic even after 500 years of use of ammonium sulphate, with an application of 50 lbs. N per acre per year (250 lbs. ammonium sulphate per acre per year).

Ammonium sulphate is a soluble fertiliser. But in spite of its high solubility, the fertiliser is not lost in leaching because of the adsorption of ammonium by soil colloids. On gradual release of the ammonium radical by nitrification to nitrate, the nitrogen can be lost, but since nitrate is being formed gradually, loss in drainage is minimised if plant roots are present to absorb the nitrate.

Ammonium sulphate fertiliser is not highly hygroscopic and has good storage qualities.

The acid or base equivalent of nitrogen fertilisers is given in Table 15.1.

3. CALCIUM AMMONIUM NITRATE (CAN) 20.5% N

Ammonium Nitrate is a concentrated fertiliser and contains about 33% N. It is manufactured by passing ammonia and oxygen gas with air over a platinum catalyst to form nitric acid. The acid is neutralized with ammonia to form ammonium nitrate.

TABLE 15.1

ACID OR BASE EQUIVALENT OF NITROGEN FERTILISERS

Fertilisers	N Content %	Acid or Base Equivalent Rated as Kg. $CaCO_3$ per 50 Kg. of Nitrogen	
		Acidic	Alkalinity
Ammonium sulphate	20.6	265	
Ammonium nitrate	33	90	
Calcium ammonium nitrate	20.5	0	0
Ammonium sulphate nitrate	26	165	
Urea	45	150	
Ammonium chloride	25	256	
Anhydrous ammonia	82	90	
Sodium nitrate	16		90
Calcium cyanamide	21		150
Calcium nitrate	15		68

Ammonium nitrate is an excellent fertiliser but it has some undesirable features. It is highly hygroscopic and it forms hard lumps, thus it is difficult to distribute in the field. It is also explosive, under pressure, and requires careful storage and handling. To avoid the objectionable features of this fertiliser, it is mixed with conditioning agents to provide granular structure and to reduce its hygroscopic nature. Ammonium nitrate during its manufacture (ammonium nitrate liquor) is mixed with limestone to form granular calcium ammonium nitrate. This fertiliser has the following average composition.

Ammonium nitrate (NH_4NO_3)	59.0% (i.e. 20.6%N)
Calcium carbonate ($CaCO_3$)	35.5%
Magnesium carbonate ($MgCO_3$)	5.5%

Calcium amonium nitrate is a neutral fertiliser that contains 20.5% Nitrogen (N), of which half is nitrate nitrogen and the other half ammonium nitrogen. With its nitrate nitrogen, the plants derive immediate benefit. Ammonium form of nitrogen provides a steady source of nitrogen which

is absorbed by the plant for a longer period. Besides, the fertiliser is readily soluble and leaves no residue in the soil.

Due to additional content of 35.5% calcium carbonate and 5.5% $MgCO_3$, the physical condition of the fertiliser is good and carries no risk of fire and explosion. Besides, calcium is an essential nutrient and is especially needed by plants on acid soils. The amount of calcium carbonate added with the calcium ammonium nitrate fertiliser at the levels of nitrogen application would be too small to have any significant affect in raising soil pH of acid soils. Unlike acid-forming ammonium sulphate, in calcium ammonium nitrate the residul acidity has been eliminated by the presence of calcium and magnesium carbonate.

Calcium ammonium nitrate can be mixed -with other fertilisers only when the mixture is intended to be used within a few days after mixing. Mixing with the following fertilisers is inadvisable, due to losses of ammonia : All fertilisers containing free lime (CaO), such as calcium silico-phosphates, basic slag, calcium cyanamide, quick (burnt) lime, and hydrated lime.

In India calcium ammonium nitrate fertiliser is being manufactured by the Nangal plant in Punjab State which has a production capacity of 82,480 tons of nitrogen annually. This fertiliser is also being produced by the Rourkela plant in Orissa State with an annual capacity of 60,880 tons of nitrogen.

4. AMMONIUM SULPHATE NITRATE (ASN) 26% N

This is a double salt of ammonium sulphate and ammonium nitrate. The proportion of the two salts is so adjusted (roughly 1 : 1) to produce relatively less hygroscopicity than that of ammonium nitrate. It has one-fourth of its nitrogen in the nitrate form and three fourth of its nitrogen in the ammoniacal form.

Ammonium sulphate nitrate is acidic in nature, i.e., the use of this fertiliser tends to induce acidic conditions. The acid quality of this fertiliser, however, is less than that of ammonium sulphate. With the use of 100 lbs. of this fertiliser, 85 lbs. of calcium carbonate are lost from the soil, while with the use of 100 lbs. of ammonium sulphate, about 109 lbs. of calcium carbonate are lost. The loss of calcium carbonate with ammonium sulphate nitrate would be 30% less when comparison is made for the same

amount of nitrogen in the two fertilisers as ammonium sulphate nitrate contains more nitrogen per lb. of fertiliser than ammonium sulphate.

The sulphur content of ammonium sulphate nitrate (and ammonium sulphate) is also an advantage as compared to ammonium nitrate fertiliser. Though sulphur deficiency has not been reported often in India, the use of sulphate fertiliser ensures that sulphur needs would always be met with this fertiliser. In a recent study at the Indian Agriculture Research Institute, New Delhi, it was found that available sulphur supply is reduced under water logged conditions. Sulphur-containing fertilisers like ammonium sulphate or ammonium sulphate nitrate may prove superior under such conditions. This fertiliser is easily soluble and leaves no insoluble residue. The fertiliser can be mixed with all potash fertilisers and with superphosphate. The fertiliser, however, should not be mixed with fertilisers contain- free lime (CaO) such as basic slag, and calcium cyanamide ; or mixed with slaked lime.

In India this fertiliser is being manufactured in Sindri, Bihar State. The annual production is 36,000 tons of nitrogen. The production of ammonium sulphate nitrate economises on the use of gypsum ($CaSO_4$) required for ammonium sulphate manufacture in the Sindri process.

5. UREA [$CO(NH_2)_2$] 45% N

Urea is a white crystalline substance containing about 45% N (pure urea contains 46.65% N). The nitrogen content of urea is higher than that of any other solid nitrogenous fertiliser. It is manufactured by reacting anhydrous ammonia and carbondioxide gas under very high pressure. The reaction is :

$$\begin{array}{ccccccc} 2\,NH_3 & + & CO_2 & \rightarrow & CO(NH_2)_2 & + & H_2O \\ \text{Ammonia} & & \text{Carbon-} & & \text{Urea} & & \text{Water} \\ & & \text{dioxide} & & & & \end{array}$$

Urea is completely soluble in water but is utilized by common field and horticultural crops largely after conversion to ammonium and nitrate compounds. Recent work in plant physiology indicates that urea-splitting enzymes exist in plants and that urea as such can be utilised at least in limited amounts. The success of foliar sprays of urea also seems to indicate that urea can be utilized directly by plants.

Under field conditions, the urea in soil undergoes changes due to biological activity and is converted to ammonium carbonate and then to nitrates. Nitrate and ammonical forms are absorbed by plants and

utilized. The reactions in the soil are :

$$\underset{\text{Urea}}{CO(NH_2)_2} + \underset{\text{Water}}{2H_2O} \rightarrow \underset{\text{Ammonium carbonate}}{(NH_4)_2CO_3}$$

$$\underset{\text{Ammonium carbonate}}{(NH_4)_2CO_3} + \underset{\text{Oxygen}}{3\ O_2} \rightarrow \underset{\text{Nitrous acid}}{HNO_2} + \underset{\text{Water}}{3H_2O} + \underset{\text{Carbon-dioxide}}{CO_2}$$

$$\underset{\text{Nitrous acid}}{2HNO_2} + \underset{\text{Oxygen}}{2\ O_2} \rightarrow \underset{\text{Nitric acid}}{2\ HNO_3}$$

The conversion of urea into ammoniacal and nitrate forms takes about 7-14 days. Urea is liable to be lost in leaching only for 3-4 days after application. Once urea is converted to ammoniacal form it is adsorbed by soil colloids and slowly released and nitrified to nitrates.

Urea application to soil creates a small loss of calcium from the soil. The tendency to produce acidic effect is much smaller than that produced by ammonium sulphate, ammonium sulphate nitrate, and ammonium nitrate on the basis of the same amount of nitrogen per acre. Thus it is physiologically less acidic than common nitrogen fertilisers.

Urea is a more economical fertiliser per pound of nitrogen than ammonium sulphate or ammonium sulphate nitrate fertilisers.

The relative price of nitrogen fertilisers as sold to cultivators in some Indian states is given in Table 15.2.

Besides urea is a concentrated fertiliser and therefore the transportation and storage costs per unit of N for urea are considerably less than for ammonium sulphate or other solid nitrogen fertilisers.

Another advantage of use of urea as a nitrogenus fertiliser is that it can be used as spray fertiliser. A 0.5 to 2.0 per cent solution of urea has been used for various crops such as wheat, rice, potato and fruit crops.

TABLE 15.2

AVERAGE PRICE OF NITROGEN FERTILISERS IN INDIA AS SOLD FOR USE OF FARMERS

Fertiliser	Price per Pound of Nitrogen (Rs.)
Ammonium sulphate	0.79
Ammonium sulphate nitrate	0.76
Urea	0.62
Calcium ammonium nitrate	0.69

Source : Recalculated from fertiliser prices in *Fertiliser Statistics, 1962-63*, Fertiliser Association of India, New Delhi.

Note : In India the prices of nitrogenous fertilisers are fixed by the Central Government.

Urea is a concentrated fertiliser, therefore its higher concentrations may injure the plant roots if its distribution is uneven. It is desirable that urea be mixed with ashes or a small quantity of soil to facilitate an even distribution to avoid risk of injury to plants.

6. AMMONIUM CHLORIDE (NH_4Cl) 25% N

Ammonium chloride is a white crystalline fertiliser containing 25% N. It is obtained as a by-product in the soda ash industry, hence it is a comparatively cheaper fertiliser. The principle of the manufacturing process is similar to one employed to manufacture ammonium sulphate by the gypsum process. For manufacturing ammonium chloride, sodium chloride solution is treated with ammonia and carbon dioxide to form sodium bicarbonate and ammonium chloride.

$$\underset{\text{Sodium chloride}}{NaCl} + \underset{\text{Ammonia}}{NH_3} + \underset{\text{Carbon-dioxide}}{CO_2} + \underset{\text{Water}}{H_2O} \rightarrow \underset{\text{Sodium bicarbonate}}{NaHCO_3} + \underset{\text{Ammonium chloride}}{NH_4Cl}$$

Like all ammonical fertilisers it is not lost in leaching because the ammonium is adsorbed on the colloidal complex of the soil. On nitrification, nitrates are produced, which is the form of N chiefly used by most plants.

Ammonium chloride removes calcium from the soil as calcium chloride and thus tends to create residual acidity. This acidic action of ammonium chloride is about the same as that of ammonium sulphate per kilogram of nitrogen used.

India has started producing ammonium chloride only in recent years. The annual production capacity by 1965-66 is likely to be 25,000 tons of nitrogen.

7. OTHER NITROGEN FERTILISERS

Sodium Nitrate : ($NaNO_3$) 16% N. Sodium nitrate (Chilean salt petre) is the oldest and best known nitrate fertiliser. It is found as a natural impure product in the interior of Chile, South America. It is now manufactured synthetically in U.S.A. and Norway.

Due to its high cost per unit of N, its low nitrogen percentage, and its properties of creating alkalinity in soil, the use of sodium nitrate has considerably decreased. The constant use of large amounts of sodium nitrate, because of the sodium, creates defloculation of clay particles and poor drainage conditions.

Calcium Cyanamide : ($CaCN_2$) 21% N. It is a non-leachable, synthetic, organic fertiliser. Small amounts of calcium cyanamide are used in some mixed fertilisers to give them a better physical condition. It is, however, a costlier fertiliser. This fertiliser, due to its free lime, should not be mixed with ammonium fertilisers or superphosphate.

Ammonia (Anhydrous) : (NH_3) 82% N. More than 90 per cent of all nitrogen fertilisers consist of ammonia or fertiliser made from ammonia. Anhydrous ammonia, liquid ammonia, ammonium nitrate, urea, ammonium sulphate, synthetic sodium nitrate, and ammonium sulphate are made with ammonia as the source of nitrogen. Only cyanamide and Chilean nitrate of soda do not use ammonia in their manufacture.

Anhydrous ammonia has been tried with success on an experimental scale in Mysore State, India. More such experiments are necessary. The results, if proved advantageous, would open the way for a cheaper source of nitrogen.* (Figure 15.1).

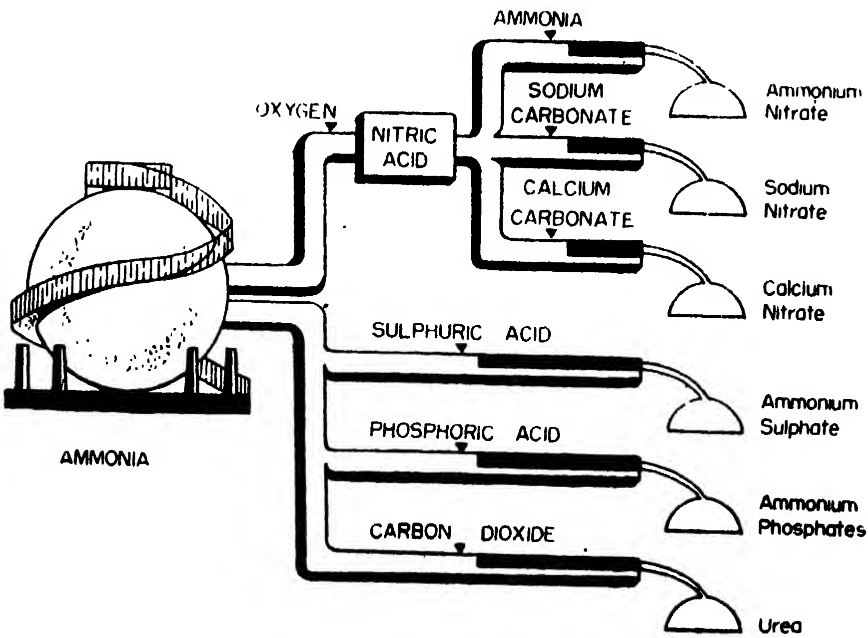

Fig. 15.1 The manufacture of nearly all nitrogenous fertilisers start from ammonia. (*Courtesy : National Plant Food Institute, U.S.A.*)

*Govinda Rajan, S. V. *Anhydrous Ammonia as a Nitrogenous Fertilizer.* Bul. No. 4, Dept. of Agriculture, Mysore State, India, 1956.

8. PHOSPHATE FERTILISERS

Phosphorus has often been called the "master key to agriculture" as low crop production is due more often to a lack of phosphorus than to the deficiency of any other element except possibly nitrogen. (The role of phosphorus in plant metabolism has been discussed under "plant nutrition", Chapter 14). The importance of phosphorus in plant nutrition was realised as early as 1840. In those days bones, which are rich in phosphate, were being imported by Britain from Europe. Leibig remarked that Britain was robbing Europe of its soil fertility. Such has been the importance of phosphate.

Phosphorus fertilisers are classified into : water-soluble, citrate-soluble, and insoluble. When the term "available P_2O_5" is used, it means water-soluble plus citrate-soluble P_2O_5.

Following are the important phosphate fertilisers being used in all parts of the world, including Tropical Asia.

Fertilisers containing water-soluble phosphorus :

1. Superphosphate (ordinary grade) (16-20% P_2O_5)
2. Concentrated superphosphate (40-48% P_2O_5)
3. Monoammonium phosphate (11% N+48% P_2O_5)
4. Diammonium phosphate (21% N+54% P_2O_5)

Fertilisers containing citrate-soluble phosphorus :

1. Dicalcic phosphate (35-40% P_2O_5)
2. Basic Slag (Indian) (3-5% P_2O_5)

Fertilisers containing insoluble phosphorus :

1. Rock phosphate (20-30% Total P_2O_5)
2. Bone Meal (3% N+18-20% Total P_2O_5)

9. SUPERPHOSPHATE

This is by far the most important phosphatic fertiliser in use all over the world. The popularity of this fertiliser is due to the fact that its phosphate is in available form and is quick acting. Long prior to the introduction of superphosphate as a fertiliser, the existence of a soluble phosphate of lime produced by the action of sulphuric acid upon ground bones was of common chemical knowledge, but the application of this knowledge to agriculture and the introduction of superphosphate began about 1840 at the Rothamsted Experiment Station, near London, England.

Manufacture : The ordinary grade of 16-20% water-soluble P_2O_5 is made by treating rock phosphate containing insoluble tricalcic phosphate with a suitable amount of sulphuric acid. A large portion of the phosphate is thus changed to the water-soluble monocalcium form.

$Ca_3(PO_4)_2$	+ $3H_2SO_4$	$\rightarrow$	$3CaSO_4+2H_3PO_4$	
Tricalcic phosphate (insoluble)	Sulphuric acid		Calcium sulphate	Orthophosphoric acid

$Ca_3(PO_4)_2$	+ $4H_3PO_4$	$\rightarrow$	$3CaH_4(PO_4)_2$
Tricalcic phosphate	Phosphoric acid		Monocalcic phosphate (soluble)

The acid is never added in amounts capable of completing the reaction, hence small amounts of dicalcic phosphate (citrate soluble) and tricalcic phosphate (insoluble) are also present.

This whole mixture is called superphosphate (ordinary grade—16-25% water soluble P_2O_5). This consists of about 31% phosphates (26% monocalcium phosphate), 50% gypsum and 19% impurities of various kinds, such as SiO_2, iron aluminium sulphate, calcium fluoride, and water.

Rock phosphate is the most common raw material available for the manufacture but, bones can also be used. The latter product is called "bone super". The chief mineral resoursces of phosphate in India are the apatites in Bihar and the phosphate nodules in Trichinopoly. The apatites in Bihar contain large amounts of silica, ferric oxide and alumina. The worst feature of Trichinopoly deposits is the high content of calcium carbonate which leads to an unduly large consumption of sulphuric acid in the manufacture of superphosphate. India also does not possess a large known reserve of phosphate except for a recent discovery in the Laccadive Islands. Because of these difficulties, rock phosphate used for manufacture of superphosphate is chiefly imported from Egypt, U.S.A., Jordan, and Morocco.

Superphosphate is a grey ash-like powder with good keeping or storage qualities. It should be stored in moisture-proof godowns to prevent the conversion of monocalcic phosphate to dicalcic or tricalcic forms.

The following standards are prescribed by Indian Standards Institution for superphosphate :

	% by weight
Moisture (maximum)	12.0%
Free phosphoric acid (P_2O_5) maximum	3.0%
Water-soluble phosphate (P_2O_5) minimum	16.0%

10. CONCENTRATED SUPERPHOSPHATE (40-48% WATER-SOLUBLE P_2O_5)

This fertiliser is also called double or triple superphosphate due to its high phosphate content. This fertiliser is formed when calcium sulphate formed in reaction No. 1 is removed and free phosphoric acid is allowed to react with rock phosphate. This means that reaction No. 1 is utilised to produce phosphoric acid while reaction No. 2 is used to produce concentrated superphosphate, as follows :

(1) $2\ Ca_3(PO_4)_2+6\ H_2SO_4 \longrightarrow 6\ CaSO_4+4\ H_3PO_4$

(2) $Ca_3(PO_4)_2+4\ H_3PO_4 \longrightarrow 3\ CaH_4(PO_4)_2$+impurities

The amount of gypsum in this product is almost negligible. The following standards are prescribed by the Fertiliser (Control) Order, 1957, of the Government of India.

	% by weight
Moisture (maximum)	12.0%
Free phosphoric acid (P_2O_5) maximum	3.0%
Water soluble phosphate (P_2O_5) minimum	40.0%

Due to high amounts of P_2O_5 it is less costly to store and transport, per unit of P_2O_5. This fertiliser is not being manufactured in India but small amounts are imported from European countries. Both superphosphate and concentrated superphosphate are physiologically neutral in their reaction with soil.

11. AMMONIUM PHOSPHATE

Two types of ammonium phosphate are available. Monoammonium phosphate (11% N. and 48% P_2O_5) and diammonium phosphate (21% N and 54% P_2O_5). Both grades are manufactured by (1) reaction of nitric or sulphuric acid on rock phosphate to produce phosphoric acid or (2) reaction of phosphoric acid with ammonia.

$Ca_3(PO_4)_2+3H_2SO_4 \longrightarrow 2H_3PO_4+3\ CaSO_4$

$H_3PO_4+NH_3 \longrightarrow NH_4H_2PO_4$ Mono—ammonium phosphate

$H_3PO_4+2NH_3 \longrightarrow (NH_4)_2\ HPO_4$ Diammonium phosphate

Ammonium phosphate is greyish in colour and least hygroscopic ; hence, it has excellent storage qualities. Its phosphate is available to plants because it is water soluble. It supplies both nitrogen and phosphate and is used in preparing fertiliser mixtures. Its production and use is increasing in India, Pakistan, and in other countries.

Nitrogen and soluble phosphate fertilisers differ in their behaviour when added to the soil. Nitrogen fertilisers when added to the soil remain in available form while phosphate when added to the soil becomes largely unavailable to the plant. Only a small part remains soluble and available to plants. This phenomenon has been termed phosphate fixation. The magnitude of phosphate fixation varies with soil type. In general, acidic soils and soils containing large quantity of calcium carbonate would fix large quantity of soluble phosphate. This is important in evaluating the responses of crops to phosphate application. Phosphate fertilisers would thus give slow residual effects for some years.

12. CITRATE-SOLUBLE FERTILISERS

Dicalcic Phosphate (35-40% citrate soluble P_2O_5). Sulphuric acid is allowed to react with rock phosphate and the resulting slurry is treated with limestone to form dicalcic phosphate. It has high amounts of citrate-soluble phosphate and has an excellent physical condition. Due to its phosphate in dicalcic form, it is cheaper and there are less chances for fixation. At the same time it is fairly available to plants.

13. BASIC SLAG

Basic slag is a by-product from steel furnaces in which the pig iron from blast furnaces is heated in contact with a furnace lining of lime to remove phosphorus and other impurities. While Europeon and American basic slags contain about 13-16% citrate-soluble P_2O_5, Indian basic slags contain only 3-5% citrate-soluble P_2O_5. Besides phosphate, it contains lime, silica, magnesium, manganese, iron, and other impurities.

Basic slag is dark gray in colour and must be ground so fine that 80% of it passes through a 100-mesh sieve. It is more effective in soils with high rainfall and that are neutral to acidic in soil reaction. It is advisable to apply it in heavy applications and about a month before sowing the crop to compensate for its slow action. Basic slag has considerable residual action.

14. INSOLUBLE PHOSPHORUS FERTILISERS

Rock Posphate (20-30% Total P_2O_5) consisting largely of tricaicium phosphate $Ca_3(PO_4)_2$, occurs in large deposits throughout the world. The United States of America possess the largest known deposits of phosphate rock

in the world. Other important deposits occur in Morocco, Algeria, Tunisia, Egypt, Russia, and Poland.

For India and Asian countries, rock phosphate comes chiefly from North African countries and the U.S.A. Is main use is for the manufacture of superphosphate. Rock phosphate due to its insoluble phosphate finds little use as a direct fertiliser except for acid soils. It is recommended that rock phosphate be used instead of superphosphate on acid soils since the latter would largely become unavailable, while the former would become slowly available due to soil acidity.

For effective results, rock phosphate should be used in heavy applications, particularly with green-manures crops, since legumes are more efficient in utilizing phosphate than grain crops. Acid areas found in Kerala, Assam, West Bengal, and East Pakistan and parts of Indonesia are suitable for direct application of rock phosphate.

Bone meal (3% N, 18-20% P_2O_5). The use of bones as a manure is an ancient practice and it is now impossible to know its origin. They have been employed as a fertiliser material as early as 1653. In earlier times, bones were used as such after grinding. Now they are converted into a variety of products like glue, gelatine, fats, and bone meal. In India bone meal is prepared by removing the fat by fat solvents such as benzene or low pressure steam. Nitrogen compounds are not usually removed. Removal of fat aids in grinding. Bone meal is obtainable in various grades of fineness. The phosphate present is in the form of insoluble tricalcic phosphate and compares with rock phosphate in action with soil. In England and U.S.A. the bones are processed to the extent to produce many by-products like fat for soap, glue, and gelatine. When the bones so treated are ground to a powder it is sometimes referred to as steamed bone flour. Rock phosphate (25% Total P_2O_5) is in an insoluble condition but is somewhat quicker in action than bone meal because of its fineness. This bone flour is often used in mixed fertilisers to the extent of 5% to act as a drier and to improve the physical condition of the mixture.

The average annual collection of bones in India amounts to about 150,000 tons. This is only one-fourth of the estimated quantity available, judging from the number of cattle that die in a year.

Bone meal is very safe and contains a considerable amount of phosphate, but it is slow acting. In combination with ammonium sulphate or green-manures, it is more effective in increasing crop yields than when used alone. Bone meal gives best results on acid soils since its phosphorus is rendered soluble by the acid and hence, it is available to plants. East Pakistan soils that have an acid reaction are responsive to bone meal.

In India bone meal is costly due to the high export value for the manufacture of many by-products. After sterilization, bone meal or bone flour are also used as a mineral supplement feed for cattle and poultry. Because of its high cost, it is not much used as a straight fertiliser. It finds its place however in the preparation of fertiliser mixures.

15. POTASSIUM FERTILISERS

Soils of arid and semiarid areas are generally well supplied with potassium. With the use of nitrogen and phosphate fertilisers on the increase, the need for potassium has also been felt in certain areas of India. Japan uses potassium fertilisers on a large scale for rice production. Acid areas usually need potassium fertilisers more than neutral to alkaline soils because acid soils have developed in areas of high rainfall that leaches out available potassium.

There are two chief potassium fertilisers.

(1) Muriate of potassium

(2) Sulphate of potassium

Both are imported by India and Pakistan. There is no indigenous production.

Muriate of Potassium (60% K_2O). This is the chief form of potassium fertiliser used. It is a coarse or fine crystalline salt. Muriate of potassium is usually 95 per cent KCl, equivalent to 60% K_2O. Deposits in U. S. A., and Germany contain approximately 40% KCl. Purification increases the concentration to approximately 95% KCl.

Sulphate of Potassium (50% K_2O). This is most expensive potassium fertiliser. It is made from muriate of potassium and is also found as such in U. S. A. Potash mineral containing $K_2SO_4 \cdot 2\ MgSO_4$ is also utilized for preparing sulphate of potassium. To a solution of $K_2SO_4 \cdot 2\ MgSO_4$, a concentrated solution of KCl is added which precipitates potassium sulphate, due to differences in solubility.

$$K_2SO_4 \cdot 2MgSO_4 + 4KCl \longrightarrow 3K_2SO_4 + 2MgCl_2$$

All potassium fertilisers are physiologically neutral in their reaction with soils.

16. FERTILISER INDUSTRY

Due to the pressing need for increasing food production, the production and use of fertilisers have been considerably stepped up in India, Pakistan and

other countries of Tropical Asia. The progress of fertiliser production from 1951-52 to 1960-61 for a few countries of Asia is indicated in Table 15.3. Figure 15.1 and 15.2 shows the production, consumption and targets of fertilisers in India.

There has been a very large increase in the production of nitrogen fertiliser since the crops have been responsive to nitrogen application. The production of phosphate and potassium fertilisers has been slow.

Ammonium sulphate has been the chief nirtogen fertiliser in India, Pakistan, Taiwan, and Korea. In recent years there is large increase in the production of urea and ammonium nitrate fertilisers. In India by the end of Third Five Year Plan, urea would account for 50 per cent of nitrogen capacity.

Synthetic ammonia represents roughly 80 per cent of the world nitrogen capacity, whereas before World War II, 90 per cent was based on coal and coke. It is estimated in "Nitrogen" magazine of the British Sulphur Corporation that the basis of world ammonia synthesis is now as follows : natural gas 31 per cent, fuel oil 15 per cent, refinery gases 9 per cent, coal and coke 40 per cent, others 5 per cent. The key role of ammonia in manufacturing a large number of nitrogen fertilisers is illustrated in Figure 15.1, page 304.

TABLE 15.3

PRODUCTION OF FERTILISERS IN CERTAIN COUNTRIES OF ASIA (IN THOUSAND METRIC TONS)

Country	1951-1952			1960-1961		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
India	23.1	9 1	0.44	109.9	57.9	0.96
Japan	456.0	268.0	*—	1029 9	514.6	—
Pakistan	—	—	—	10.3	1.3	—
Korea	—	0.2	—	19.7	—	—
*Philippines	6.0	—	—	7.4	6.0	—
Taiwan	13.8	12.3	—	50 1	27.8	—

* Figure refers to 1953-54.

Source : F.A.O. Rome, *An Annual Review of World's Production and Consumption of Fertilisers*, 1953 and 1962.

Superphosphate and muriate of potash are the chief sources of phosphate and potassium fertilisers, respectively, for soils in Tropical Asia.

17. FERTILISER MIXTURES

When we say that soil is low in nitrogen or phophorus or any other nutrient, it does not follow that all soils have same requirement of fertilisers. The soils testing 25 lbs. or 49 lbs. P_2O_5 per acre are both classed as medium in

available phosphorus and still the requirement would vary. Some soils may be deficient in nitrogen only while others may be deficient in nitrogen and phosphate, still others may lack nitrogen, phosphorus and potassium. Thus the soils vary in their ability to supply available nutrients. To suit the variable requirements of different soils and crops, fertiliser mixtures are prepared. A mixture of two or more fertiliser materials is referred to as fertiliser mixture or mixed fertiliser. The fertiliser materials often used contain a single nutrient but may contain two nutrients; ammonium phosphate is one example which contains two nutrients.

Composition of fertiliser mixtures: The chemical composition of a fertiliser mixture is expressed in three figures to give the percentage of N, P_2O_5 and K_2O, in that order. For example, a fertiliser mixture of 12-6-6 grade in India means that the mixture has 12 per cent of total nitrogen, 6 per cent of water-soluble P_2O_5 and 6 per cent of water-soluble K_2O.

It is not practicable to add exact quantities of various fertiliser ingredients. Usually little more of nutrients than acually required are first added and the correct grade is made by the addition of inert or conditioning substances. The conditioning is often necessary to adjust the mixture to the correct grade and to improve the physical condition of the mixture. The addition of limestone is sometimes made to correct the residual acidity.

Various formulations of fertiliser mixtures are necessary to suit varying requirements of soils. The formula showing the kind and quantity of each material contained in it is called an open formula. When the ingredients added in mixture are not disclosed it is called a closed formula. The open formula permits the extension worker and the farmer better judgment as to the quality of the material suited to the particular requirement.

When more than one nutrient is needed, equally good results can be obtained by application of single nutrient fertilisers. But the cost of such application would rise. The advantages of fertiliser mixtures are summarised as follows :

(1) The cost of application of two or more fertilisers is higher than the cost of a single application of a fertiliser mixture.

(2) Fertiliser mixtures permit the use of correct amounts for various soils and crops according to their requirements. This avoids wastage and affords more economical use of fertiliser material.

(3) Fertiliser mixtures can be prepared in a manner to correct residual acidity of certain nitrogen fertilisers.

(4) In a country where farmers have to be made fertiliser conscious, the use of fertiliser mixtures offers the best scope for popularising balanced fertiliser use. The use of more than one fertiliser to

correct deficiencies of more than one nutrient may confuse the farmer.

(5) Fertiliser mixtures can be so prepared as to include certain essential nutrients for a specific area.

(6) The physical condition of the fertiliser is important in the promotion of fertiliser distribution. The mixtures can be so prepared as to have the right physical condition.

There are certain disadvantages in the use of fertiliser mixtures which are enumerated here :

(1) The use of mixed fertilisers is not always economical in terms of labour costs. Besides the use of mixed fertilisers, single nutrient fertiliser may still be necessary at a specific plant growth stage. For example, nitrogen in split application, i.e., at 2 or 3 stages of plant growth, has given higher crop responses. With the use of mixed fertilisers containing nitrogen and phosphorus, the application of nitrogen fertiliser would still be necessary at tillering and/or flowering stage. If only mixed fertiliser is used, full advantage of split application of single fertiliser nutrient cannot be obtained.

(2) Fertiliser mixtures of various grades are necessary for even single application. The purchase and use of correct formulation requires relatively greater knowledge. Lack of proper knowledge about the proper mixture for a specific soil type and for a particular crop may result in improper use.

(3) The cost per unit of nutrient is always higher in a mixture than in a single fertiliser material, due to cost involved in preparation of the mixture.

(4) Fertiliser mixtures contain a lower percentage of nutrients than the fertilisers from which they are made. Thus for certain weight of nutrients, more material of mixture is to be transported than the combined weight of single fertilisers. For example at the level of 20 Kg. N and 20 Kg. P_2O_5 per acre, 250 Kg. of fertiliser mixture (8-8-0) would be needed. On the other hand, about 100 Kg. of ammonium sulphate and 120 Kg. of superphosphate would total 220 pounds, or a saving of 30 pounds less to be transported.

(5) While it is usually advantageous to place phosphate fertilizer below and to one side of the seed or plant, the mixing of ammonium or urea fertiliser with the soil is sometimes desirable. The use of fertiliser mixtures does not permit such differential application.

The preparation of fertiliser mixtures requires technical knowledge to avoid use of incompatible fertilisers. Chemical reactions between fertiliser

ingredients can cause a loss of nutrients. For example mixing of ammonium sulphate with lime will cause loss of ammonia. Loss of nitrogen would also occur by mixing sodium nitrate with superphosphate or mixing an ammonium fertiliser with calcium cyanamide because calcium cyanamide contains free lime.

The plant nutrients can be converted to less available form due to improper mixing. For example mixing of superphosphate with calcium cyanamide or lime causes reduced availability of phosphate.

Further, the improper mixing may result in poor physical conditions. In some cases a hard lumpy mass may result that would require breaking up before distribution ; in other cases a damp product may result which is difficult to apply. For example the mixture of sodium nitrate and ammonium phosphate, if kept for some time would result in a hard lumpy mass.

Grades of fertiliser mixtures used in various states of India : As the fertiliser use is increasing, the consciousness and knowledge of mixed fertilisers is growing among farmers in India. A number of fertiliser grades are in current use in different parts of India. Fertiliser mixtures to be applied at planting time approved by Andhra, Madras, and Punjab are given in Table 15.4.

Some states have been cautious in introducing mixtures and only a few grades have been recommended. Kerala state has acid soils, hence, uses all three plant nutrients in the mixtures on a relatively larger scale.

TABLE 15.4

FERTILISER MIXTURES TO BE APPLIED AT PLANTING TIME APPROVED BY SOME INDIAN STATES

Nutrient Ratio	Andhra Pradesh	Madras	Maharashtra	Punjab	Kerala
1-1-0	10-10-0		9-9-0	9-9-0	9-9-0
1-2-0	6-12-0	6-12-0	6-12-0		
2-1-0	12-6-0	12-6-0	12-6-0		
1-2-2	5-10-10	5-10-10			5-10-10
1-1-1	8- 8-8	8-8-8		8-8-8	8- 8-8
					9- 9-9
1-2-1	6-12-6				7-14-7
2-1-4					8-4-16
1-1-2					8-8-16
2-1-1					12-6-6

Source : *Fertiliser Statistics*, 1962-63, Fertiliser Association of India, New Delhi.

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FERTILISERS AND THEIR USE

" A field without manure (fertiliser) is as worthless as a cow without a calf."

ANCIENT TELUGU PROVERB

Without chemical fertilisers the world population would probably soon exceed its food supply. With fertilisers and other essentials of agricultural production such as improved seed, better insecticides, and a more adequate irrigation water supply, a critical population pressure upon the land can be delayed perhaps indefinitely.

Based upon past records, it is expected that the world production of fertilisers will increase approximately 6 per cent each year, or will double every 15 years. This rate of fertiliser production should be sufficient to help feed a growing population if the food production of the world is shared. Neverthless, because of national pride and economics each country strives toward higher agricultural production levels to attain self sufficiency. Fertiliser production and consumption must keep pace with growing populations so that each country can attain its goal.

Asian countries, with exception of Japan, have started using fertilisers on an extensive scale only recently. The level of fertiliser consumption has been steadily increasing in Asian countries but there are still higher targets to be reached to feed their increasing populations.

TABLE 16.1

CONSUMPTION OF FERTILISERS IN INDIA

Year	N	P_2O_5	K_2O
	(Thousand metric tons)		
1948–49 to 1952-53	63.10	11.50	3.20
1953–54	84.86	14.17	5.26
1954–55	117.14	15.44	10.20
1955–56	138 00	18.00	14 00
1956–57	165.05	17.74	8.00
1957–58	178.74	25.96	19.95
1958–59	179 94	34 60	18.84
1959–60	230.24	66.35	31.92
1960–61	283.10	58 05	28.92

Source FAO Yearbooks.

I. FERTILISER CONSUMPTION

India: Table 16.1 gives the consumption of N, P, K fertilisers in India. The consumption of nitrogen fertilisers has increased tremendously but the consumption of phosphate fertilisers has not kept pace with the nitrogen consumption. Large use of nitrogen fertilisers has increased the crop yields, resulting in greater uptake of phosphorus and other nutrients. Some farmers complain that nitrogen fertilisers have ceased to give the response which was obtained when nitrogen fertilisers were first used. This shows the need for phosphate .and/or other nutrients. Steward reported as early as 1946 that the view about Indian soils not needing phosphates is held to a large extent by Indian scientists but not by enlightened farmers.

Table 16.2 gives the consumption of major fertilisers nutrients in each State of India. It would be seen that Andhra, Kerala, and Madras use the highest amounts (7-10 lb. of fertilisers, $N+P_2O_5+K_2O$), while Rajasthan, Madhya Pradesh, Orissa, and Assam use the smallest amounts of fertiliser nutrients (less than the one pound per acre). Fertilisers when combined with good seed and adequate water supply give the highest response. Special efforts are needed in irrigated areas to bring out the greatest returns from the land. To achieve maximum consumption of fertilisers, they must be available within bullock cart distance of every farmer. (Figure 16.1.)

The Planning Commission of India with the advice of Indian Soil Scientists has fully appreciated the needs of soils and crops for balanced fertilisation. This is reflected in the production and consumption targets for the Third Five Year Plan in Table 16.3. on Page 320.

TABLE 16.2

CONSUMPTION OF FERTILISERS PER UNIT AREA OF AGRICULTURAL LAND, BY STATES, IN INDIA, 1962-63

State	Consumption in lb. per acre				Consumption in kg. per hectare			
	N	P_2O_5	K_2O	Total	N	P_2O_5	K_2O	Total
Andhra Pradesh	6.05	1.60	0.03	7.68	6.77	1.79	0.04	8.60
Assam	0.10	0.07	0.11	0.28	0.11	0.08	0.12	0.31
Bihar	1.80	0.27	0.10	2.17	2.02	0.31	0.11	2.44
Gujarat & Maharashtra	1.33	0.59	0.09	2.01	1.49	0.66	0.10	2.25
Jammu & Kashmir	1.18	0.01	—	1.19	1.33	0.01	—	1.34
Kerala	3.51	0.75	4.10	8.36	3.94	0.84	4.60	9.38
Madhya Pradesh	0.62	0.14	—	0.76	0.69	0.16	—	0.85
Madras	7.71	1.03	1.04	9.78	8.64	1.16	1.17	10.97
Mysore	1.84	0.53	0.36	2.73	2.06	0.60	0.40	3.06
Orissa	0.72	0.13	0.02	0.87	0.81	0.15	0.02	0.98
Punjab	2.79	0.21	0.01	3.01	3.12	0.24	0.01	3.37
Rajasthan	0.35	0.08	—	0.43	0.39	0.09	—	0.48
Uttar Pradesh	1.80	0.17	—	1.97	2.02	0.19	—	2.21
West Bengal	1.74	0.76	0.48	2.98	1.95	0.85	0.53	3.33
Delhi	2.30	0.14	—	2.44	2.58	0.16	—	2.74
Himachal Pradesh	0.22	0.21	—	0.43	0.25	0.23	—	0.48
Manipur	0.18	0.09	—	0.27	0.20	0.10	—	0.30
Tripura	0.02	—	—	0.02	0.03	—	—	0.03
Andaman & Nicobar	0.48	—	—	0.48	0.54	—	—	0.54
Total for India	2.24	0.49	0.19	2.92	2.51	0.55	0.22	3.28

Note : Calculated on the Basis of Distribution Figures.

Source : *Fertiliser Statistics, 1962-63.* Fertiliser Association of India, New Delhi.

Fig. 16.1 Fertilisers should be stocked within bullock cart distances of every farmer, as indicated by this village fertiliser supply depot in Central India.

TABLE 16.3

TARGETS OF PRODUCTION AND CONSUMPTION OF NITROGEN, PHOSPHORUS, AND POTASSIUM FERTILISERS IN INDIA DURING THE THIRD FIVE-YEAR PLAN

Year	Production			Consumption		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
			(thousand metric tons)			
1961-62	140	100	—	400	100	82
1962-63	200	150	—	525	150	100
1963-64	300	225	—	650	225	130
1964-65	500	300		800	300	160
1965-66	800	400	·	1000	400	200

Source : *Third Five-Year Plan*, 1961. Government of India--Planning Commission.

Taiwan : The consumption of all the three N P & K fertilisers has been steadily rising. The figures indicate an increase of more than 100 per cent in 1960 when compared to consumption in 1950. Agricultural workers in Taiwan have set the target for a further rise in the consumption of fertilisers, particularly phosphate and potassium fertilisers, to provide for an N : P_2O_5 : K_2O ratio of 1: 0.5 : 0.5 in 1964. Thus in recent years, there is a trend toward a better balanced fertiliser application. The future trend is toward an increase in the proportion of K_2O and a lowering of that of N, although the absolute amount of nitrogen fertiliser consumed will continue to lead by a wide margin. Table 16.4.

TABLE 16.4

CONSUMPTION OF FERTILISERS IN TAIWAN

Year	N	P_2O_5	K_2O
	(thousand metric tons)		
1950	48.71	12.79	1.33
1955	83.34	29.08	17.37
1960	94.92	27.78	26.58

Source : *Soils and Fertilisers in Taiwan.* Published by the Society of Soil Scientists and Fertiliser Technologists of Taiwan. 14, Wenchow St., Taipei, Taiwan, 1961.

Pakistan : The consumption trends of the three types of fertilisers is similar to that of India. There has been a steady increase in the use of all the three types of fertilisers but the proportion of N : P_2O_5 is 1 : 0.17 and is unbalanced as in India (1 : 0.21).

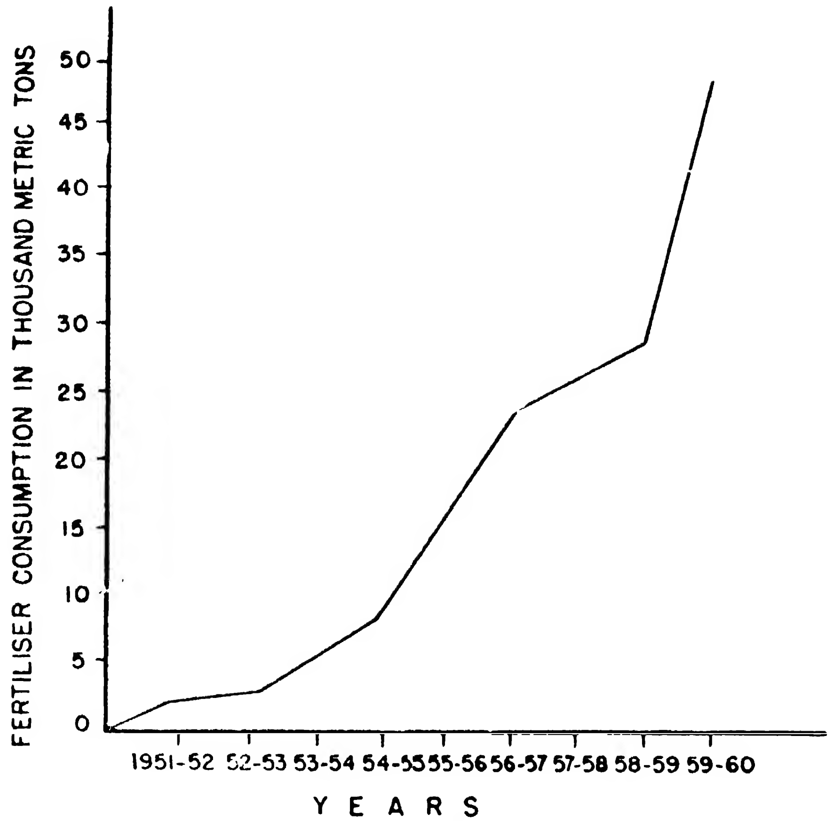


Fig. 16.2 Fertilizer Consumption in East Pakistan. *Source* : M A. Islam (1961) *Fertilizer Use in East Pakistan*, Department of Agriculture, East Pakistan, Dacca).

The fertiliser programme in East Pakistan is relatively more recent. The consumption of the fertilisers has been steadily rising and is illustrated in Figure 16.2. Most of the fertiliser used is nitrogenous, although some bone meal and superphosphate are also used. (Table 16.5.)

Thailand : The increase in fertilisers of all kinds has risen from 9,360 tons in 1950 to 47,640 tons in 1959, in terms of materials. This increase has resulted due to intensive efforts to raise crop yields. The consumption figures are given in Table 16.6. The significant feature is the great increase of mixed fertilisers of NP and NPK group which indicates the stress laid on the use of balanced fertilisers.

Viet Nam: No exact data of the fertiliser consumption is available for Viet Nam. It is said that chemical fertiliser has been used for about 30 years. Before the World War II, only 12,000 to 20,000 metric tons of

TABLE 16.5

CONSUMPTION OF FERTILISERS IN EAST AND WEST PAKISTAN

Year	N	P_2O_5	K_2O
	(thousand metric tons)		
1948-49 to 1952-53	5.00	0.10	—
1953-54	10.83	--	—
1954-55	12.14	0.05	--
1955-56	8.20	0 08	0.005
1956-57	39.10	2.70	0.15
1957-58	10.56	0 43	0.12
1958-59	13.36	0.36	0 12
1959-60	34.05	5 38	0 18
1960-61	70 04	14.96	9.03
1961-62	62.06	10 65	6.04

Source : FAO Yearbooks.

fertilisers were imported annually. Since 1954, the total quantity of fertiliser imported has been steadily rising ; in 1958 it was 40,000 tons and in 1959 it was 120,000 metric tons.

Ammonium sulphate is the most popular fertiliser, representing about 50% of the total fertiliser used. Tricalcium phosphate is the most popular phosphorus fertiliser.

TABLE 16.6

FERTILISER CONSUMPTION IN THAILAND

Fertiliser	Amount Imported and Consumed		
	1950	1955	1959
	(thousand metric tons)		
Nitrogen	8.70	19 59	23.40
Phosphorus	0.56	3.02	1.27
Potassium	0.06	0.51	1.28
NP—NPK Mixtures	0 024	1.06	21.58
Other	0.014	0.09	0.11
Total	9.36	24.27	47.64

* *Notes :* (1) Figures are in terms of fertiliser materials.

(2) All fertiliser consumed is imported, since there is no domestic production.

Source : O.B. Anderson (Ed.) Far East Fertiliser Workshop, Taipei, Taiwan. 1960.

Philippines : The total fertiliser production in Philippines is 91,571 metric tons and the present total consumption of fertilisers is 257,071 metric tons. The balance is imported.

Before World War II, most of the fertiliser was used by the sugarcane planters of the Philippines. The sugar industry consumed about 70 per cent of the fertilisers. The main reason for the increased use of fertilisers by the sugar industry was the assurance of demand and a stable price of sugar in the world market. At present the sugar industry is still the largest consumer of fertilisers (89,500 metric tons) consuming 34.6 per cent of the total fertilisers. Rice and maize farmers consume annually 69,000 metric tons, i.e., 26.8 per cent of the total fertilisers consumption. The other crops such as coconut, tobacco, citrus, coffee, cacao, and vegetables use 98,571 metric tons or 38.4 per cent.

Indonesia : The consumption of both nitrogen and phosphate fertilisers has remained fairly steady except in 1959-60 when nitrogen fertiliser use was high. (Table 16.7.)

TABLE 16.7

FERTILISER CONSUMPTION IN INDONESIA

Year	N	P_2O_5	K_2O
		(Thousand metric tons)	
1953-54	18.93	9.70	0.70
1954-55	22.00	7.00	2.50
1957-58	23.58	12.90	—
1958-59	27.75	—	—
1959-60	45.51	8.73	—
1960-61	21.10	9.95	—

Source : FAO Yearbook.

Ceylon : The significant feauture of fertiliser consumption is the large use of nitrogen and potassium fertiliser and the small use of phosphate fertiliser. (Table 16.8).

TABLE 16.8

FERTILISER CONSUMPTION IN CEYLON

Year	N	P_2O_5	K_2O
		(Thousand metric tons)	
1956-57	25.88	2.92	40.46
1957-58	19.92	2.20	21.25
1958-59	24.94	2.69	21.48
1959-60	31.04	1.64	25.43
1960-61	29.91	2.58	27.75
1961-62	34.66	1.58	30.33

Source : FAO (1962) *Annual Review of World Production, Consumption and Trade.*

2. NUTRIENTS REMOVED BY CROPS

Crops grown on the soil remove nutrients that must be replaced. Sometimes soil minerals break down fast enough to release a large part of the nutrients found in crops but this process is too slow to provide all nutrients for high crop yields. Legumes are capable of fixing atmospheric nitrogen in amounts satisfactory for crop yields of 10 years ago, but not sufficient for today's crop yields. The nutrients removed by high yielding crops must be replaced to ensure profitable farming. Pounds per acre of the major nutrients (N, P_2O_5, and K_2O) removed by important crops is given in Table 16.9.

TABLE 16.9

PLANT NUTRIENTS REMOVED BY SELECTED CROPS

Crop			Yield lbs./acre	Nutrients removed per acre N	P_2O_5	K_2O
					Pounds	
1 Rice		Grain	2000	26	14	8
		Straw	4000	28	8	75
	Total		6000	54	22	83
2. Wheat		Grain	1400	22	12	7
		Straw	2800	13	4	35
	Total		4200	35	16	42
3. Maize		Grain	1800	32	17	10
		Stalks	3600	39	12	58
	Total		5400	71	29	68
4. *Jowar*		Grain	1000	14	9	7
		Stalks	3000	12	7	65
	Total		4000	26	16	72
5. Cotton		Seed Cotton	1500	40	16	16
		Stalks	2800	35	10	38
	Total		4300	75	26	54

TABLE 16.9 *(Contd.)*

PLANT NUTRIENTS REMOVED BY SELECTED CROPS

Crop		Yield lbs./acre	Nutrients removed per acre N	P_2O_5	K_2O
				Pounds	
6. Barley	Grain	1500	27	12	7
		2500	18	6	36
Total		4000	45	18	43
7. *Bajra*	Grain	1000	15	6	9
	Straw	3000	14	4	81
Total		4000	29	10	90
8. Soyabean	Grain	1500	110	35	40
	Stalks	300	18	6	24
Total		1800	128	41	64
9. Groundnut	Nuts	1500	45	8	8
	Vines	4500	20	4	30
Total		6000	65	12	38
10. Early Potato		10000	76	27	125
11. Late Potato		22400	92	42	188

Sources : (Lines 1-9) *Plants Need Food.* Indo-American Technical Co-operation Programme, Agriculture Section, New Delhi (Undated publication).

(Lines 10-11) A.K. Dutt (1961) *Improved Crop Varieties Need Improved Soil Fertility.* Fertiliser News, October, 1961.

Different workers have given different estimates for the nutrients removed by crops. These estimates would obviously vary depending upon the variety, soil fertility, fertiliser use, and other management factors. Improved varieties would be high yielding and would remove larger amounts of nutrients. The figures for nutrient removal can vary for different agro-climatic regions. The figures given in the Table may therefore be taken as a general guide.

MODEL OF YIELD RESPONSE CURVE

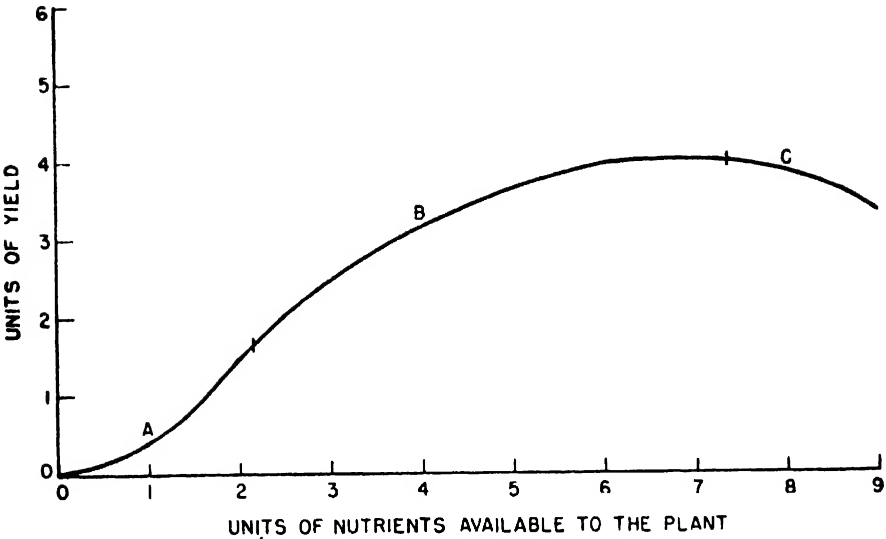


Fig. 16.3 A small amount of fertiliser may give very little initial yield, then a rapid increase in yield, as in 'A", then a levelling, as in "B". Further increases in fertiliser may give declining yields as shown in "C". The most profitable level of fertiliser is reached when the last increment is just paid for by the value of the increased yield, which may be near the maximum yield. (*Source* : Plant Food Review, Vol 3, No. 1, 1961.)

3. RESPONSE TO FERTILISERS

(A model crop yield response curve is given in Figure 16.3).

India : There have been numerous experiments in all parts of India that have shown a universal response of all crops to nitrogen. This is not surprising since the soil tests for available nitrogen have almost invariably indicated "low" values.

Extensive investigations carried out at the Central Rice Research Institute, Cuttack, Orissa, have shown that a universal response of paddy to 40 lbs. N. per acre can be expected. This has generally been the response also in Model Agronomic Trials in various agro-climatic zones. The response with the first 20 lbs. N. is greater than with second 20 lbs. N. The response with 40 lbs. N. is economic; and larger total profits are obtained with 40 lbs. N than with 20 lbs. N. The cost of fertilisers is less than half of the value of the additional food grain obtained. An increased yield of 250-550 lbs. paddy per acre was obtained with 40 lbs. N. per acre. The

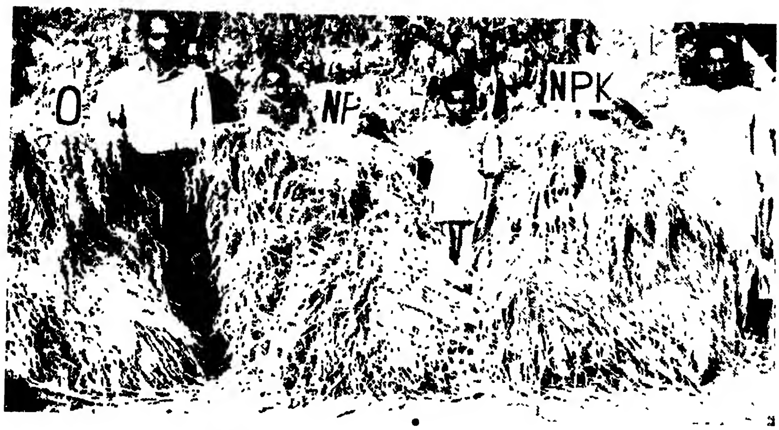


Fig. 16.4 The State fertiliser recommendation increased paddy yields in Khumaria village near Jabalpur, Madhya Pradesh India, 21 per cent while the State recommendation plus 30 pounds of K_2O increased yields 48 per cent, over the plot not fertilised O—No fertiliser. Yield : 1,345 pounds of paddy per acre NP—30 pounds of N and 30 pounds of P_2O_5 per acre (The generalized State recommendation) Yield : 1,628 pounds of paddy per acre. NPK—30 pounds of N, 30 pounds of P_2O_5 per acre Yield : 1,998 pounds of paddy per acre. *Note :* When N was applied 1/2 was applied at puddling time and the other 1/2 four weeks after transplanting. (*Courtesy : Frank Shuman*)

Fig. 16.5 Paddy yields in Mohinia village Jabalpur near, Madhya Pradesh, India, increased 136 per cent with the use of adequate fertilisation O-- No fertilizer. Yield : 1,768 pounds per acre of paddy. NPK—40 pounds of KO per acre. Yield : 4,182 pounds of paddy per acre. (*Courtesy : Frank Shuman*)

response is approximately 10-14 lbs. paddy per pound of nitrogen applied. In some years as high as 20-30 lbs. grain was produced per pound of nitrogen applied. The response is larger when assured water supply is available, improved vareties are used, and adequate plant protection is given. (See Figures 16.4 and 16.5.)

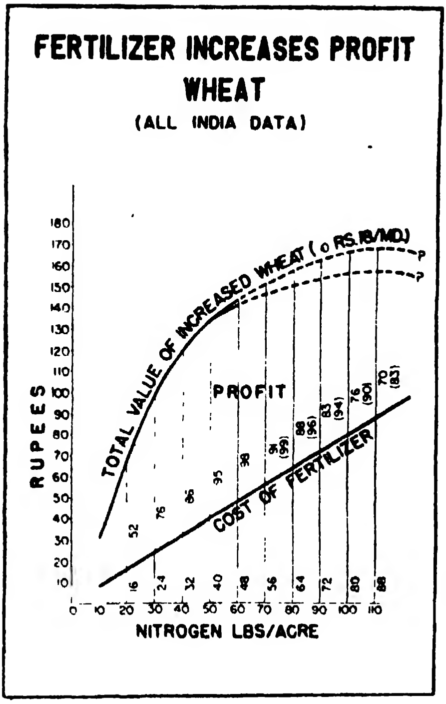


Fig. 16.6 Maximum profit from nitrogen application to wheat is obtained with 60 lbs of N per acre.

Response of nitrogen fertilisers on wheat has also been universal and only slightly less than with paddy. The economic response has been obtained up to 40 lbs. N. per acre in most places for irrigated wheat and up to 20 lbs. N per acre in rainfed areas. Increased yields of 20-70 per cent (over no fertiliser treatment) have been obtained. With the introduction of improved varieties and irrigation facilities, the yields of both the paddy and wheat were increased up to 60 lbs. N per acre. An upward trend in fertiliser response may be expected in the coming years as improved cultural practices are used with better timeliness and precision and in proper combinations.

The response of sugarcane to nitrogen fertilisers has been well known ; in fact, sugarcane in the past has consumed a large part of total fertilisers. Optimum response to 100-125 lbs. N per acre is expected. Many other crops have also shown an economic response to nitrogen fertilisation. The response to N fertilisation to wheat and *bajra* is illustrated in Figures 16.6 and 16.7.

The response to phosphate fertilisers has nearly always been less than that to nitrogen. The low nature of response was particularly obtained in the thirties and forties. In recent experiments on cultivators' fields, started in 1950-51, the response to phosphorus fertilisers has tended to increase substantially and only slightly less than that to nitrogen. This can partly be ascribed to better methods of application such as placement, or to the phosphatic fertilisation of legumes. Further, as the nitrogen fertiliser consumption increases, the soil becomes depleted of other nutrients and increased response to phosphates can be visualized. The response to phosphate fertilisers is likely to rise further in the coming years. The

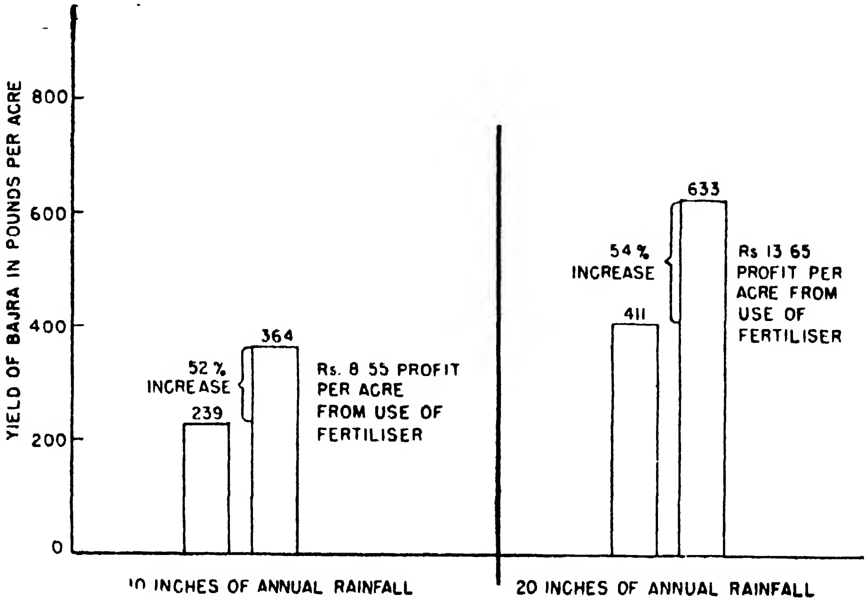


Fig. 16.7 *Bajra* Fertilisation : More than a 50 per cent increase in yield can be expected from 15 lbs. N per acre *Source :* Jain, S V., and C.M Mathur *Efficiency of Different Nitrogenous fertilisers for Bajra Production in Desert Soil of Rajasthan* The Indian Journal of Agronomy. Vol V. No. 3, March 1961.

Note : The above data are for ammonium sulphate. The comparable figures for 15 pounds N/A with urea or ammonium sulphate nitrate are the same.

response of paddy to phosphate application is somewhat greater than that with wheat. The services of India's 34 soil testing laboratory are being utilized to find the soil test values and to know the fertiliser dose needed. The lower the soil test value, the greater the response to phosphorus.

A combined application of nitrogen and phosphate gives a lower response than the sum of individual responses to 20 lbs. N : and 20 lbs. P_2O_5, but nevertheless is equal to or higher than with 40 lbs. N per acre. Combined application of nitrogen and phosphate fertilisers maintains the fertility at high level and ensures good yields. Over a 9-year period in Uttar Pradesh, wheat yields were highest with the use of *only* chemical fertilisers (N+P) than with the use of farmyard manure plus chemical fertilisers. (See Figure 16.8.) on page 339.

On Bagwai Farm in Madhya Pradesh, the response of paddy to phosphate fertilisers was higher than to nitrogen. The combination of N and P

fertilisers has been found to be particularly beneficial; 60 lbs. N+30 lbs. P_2O_5 gave the highest economic response, whereas, 60 lbs. N+60 lbs. P_2O_5 gave a slightly further increase in yield but no increase in net profits. With assured irrigation and good varieties, a substantial net profit of Rupees 96 per acre can be expected (after deducting the cost of fertiliser and assuming a stable price of grain to the farmer).

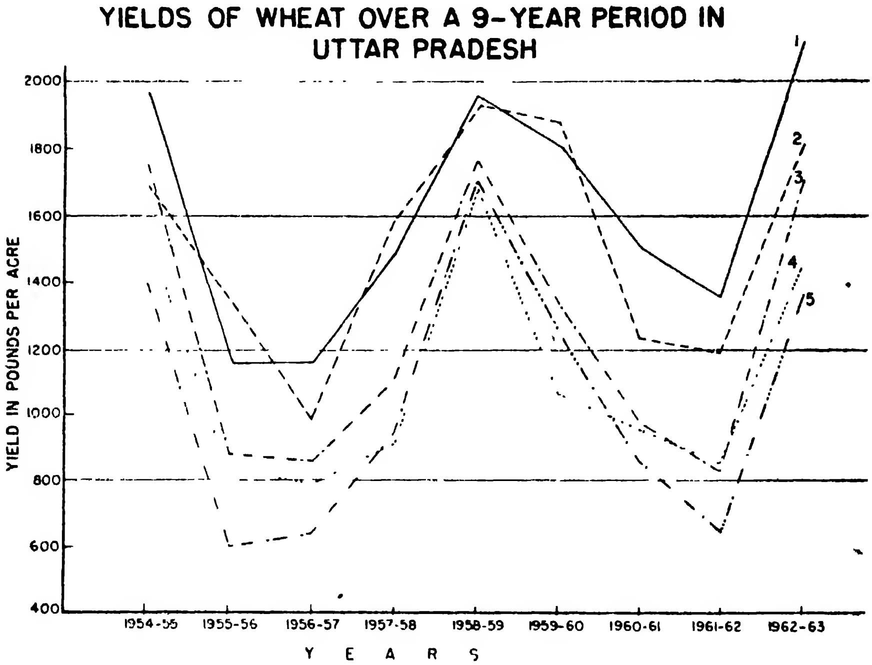


Fig. 16.8 Wheat yields in Uttar Pradesh over a nine-year period were highest with 30 lbs. N as ammonium sulphate, plus 30 lbs. P_2O_5 as superphosphate.

Legend : (Treatment per acre year) :

(1) 30 lbs. N as ammonium sulphate, plus 30 lbs. P_2O_5 as superphosphate

(2) 15 lbs N as ammonium sulphate, plus 15 lbs. N as manure, plus 30 lbs. P_2O_5 as superphosphate.

(3) 15 lbs. N as ammonium sulphate, plus 15 lbs. N as farmyard manure.

(4) 30 lbs. N as ammonium sulphate.

(5) Control (no fertiliser ; no farmyard manure)

Source : C.L. Mehrotra, *Application of Fertilisers on Wheat*. Bureau of Education and Extension, Dept. of Agriculture, Lucknow, U.P. 1963.

Note : Research was conducted at the Fertiliser Research Station, Pura (Kanpur). Utter Pradesh, India.

Fig. 16.9 Hybrid maize yield was increased more than five fold (585%) by the application of adequate fertilisers on yellow clay soil on the Agricultural College Farm, Jabalpur, M.P., India, **Left** : No fertilizer. Yield : 1,254 pounds per acre of maize on the cob. **Right** : 100 pounds of N plus 60 pounds of P_2O_5 per acre. Yield : 8,585 pounds per acre of maize on the cob.
Note : (1) The hybrid maize was Ganga 101. (2) Average annual rainfall at Jabalpur is approximately 50 inches. (3) All yields are on a 15% moisture basis. (4) Thirty pounds of N plus all of the P and K were applied between the seeds at seeding time and 70 pounds of N was applied as a top dressing one month later when the maize was knee high. *(Courtesy : Frank Shuman)*

Response to potassium fertilisers has not been universal ; in fact in some places a decrease in yield has been obtained. The response of crops such as sugarcane, tobacco, chillies, and potato to potassium can be expected in most places. The response of other crops has been small and often economic. Mukerjee in Bihar obtained an economic response to potassium fertilisers when experiments were conducted on cultivators' fields. These areas having low fertility status may normally be expected to give a higher response. Since the experiments of Mukerjee, there has been greater awareness about the need of potassium. More States have reported potassium response in certain localities. No general recommendation can be made for crops like wheat and rice but it is advisable to get the soils tested. All soils testing "low" in potassium should receive potassium fertilisers. The laterite soils and other acid soils are usually deficient in potassium and are thus more responsive to potassium fertilisers. (See Figures 16.9 and 16.10.)

Field experiments in certain selected places in India have shown the beneficial effects of micronutrients on several crops. Increased response was obtained to copper on rice and *jowar* in Maharashtra ; manganese and zinc for wheat and maize at Indian Agriculture Research Institute,

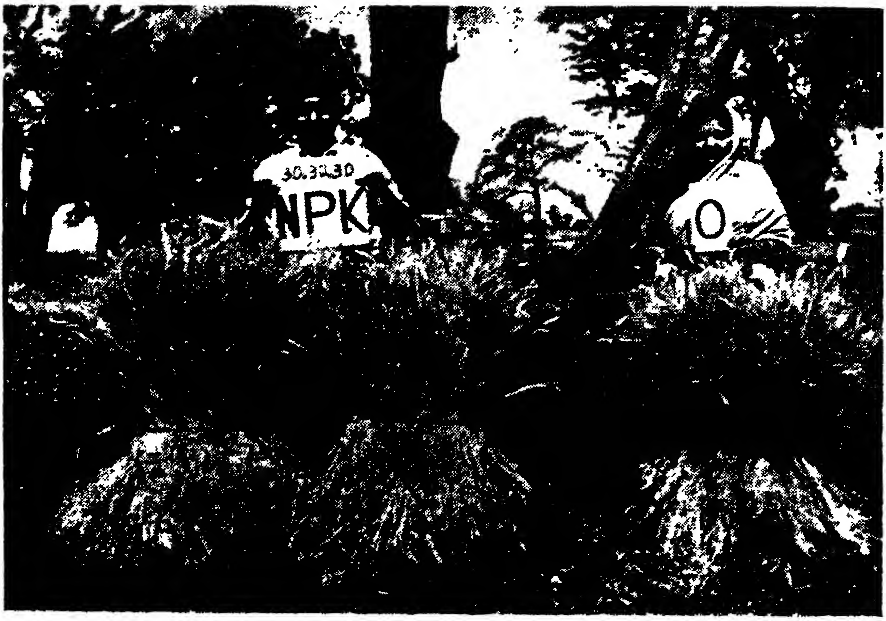


Fig. 16.10 Without rain or irrigation water (only stored soil moisture), wheat on right in both photos received no fertiliser and yielded 600 pounds of grain per acre. On the left in photos the wheat received 30 pounds per acre each of N, P_2O_5, and K_2O, and yielded 1,450 pounds of grain per acre (Near Jabalpur, Madhya Pradesh, India). (Courtesy *Frank Shuman*).

New Delhi ; boron and manganese on groundnut in Maharashtra ; boron and molybdenum for ~~berseem clover~~ at IARI, New Delhi ; manganese and zinc for cotton at Baroda and Indore ; manganese for potato and gram in Bihar ; and zinc on paddy at Coimbatore, wheat in Poona, and Ragi in Bangalore. The application of manganese increased the yield of sugarcane and improved the quality of its juice. The soil application of 14 lb. of copper (Cu) increased the grain yield of paddy from 37 to 83 per cent over control in Konkan and Poona regions in Maharashtra.

There is now greater awareness to find the response of crops to micro-nutrient application and find the best dose and method of application. Experiments have now been started at several places under the Model Agronomic Trials ; until then, no general recommendation in India can be given.

Pakistan : The results of fertiliser trials in farmers' fields in East Pakistan have been done with three types of rice, *Aman* (winter), *Aus* (autumn) and *Boro* (spring). The results indicate that the highest response was obtained with nitrogen application, followed in order by phosphorus and potassium. The response with potassium was not obtained on all soil types.

The application of mixed fertilisers gave much higher yields than that of single fertilisers; the efficiency of N P K being higher than that of N P. The average of 3 years on *aus* and *boro* and 4 years on *aman* indicate that yields of *aus*, *aman* and *boro* can be increased by 64, 57, and 50 per cent. respectively, by N P fertiliser and by 92, 78, and 62 per cent, respectively by N P K fertilisers. Average yields of *aus, aman*, and *boro* paddy due to fertiliser treatments is illustrated in Figure 16.11. On the basis of results achieved, the use of balanced fertilization to include N, P, and K fertilisers had been made for most of the areas in East Pakistan. For a few locations, the use of only N + P fertilisers is advised due to the poor response to potassium. The

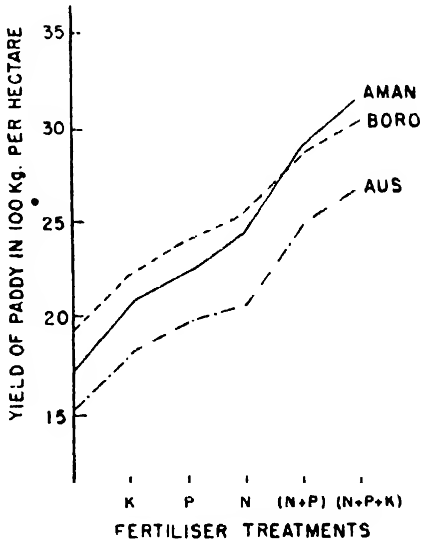


Fig. 16.11 Average Yield of *aus, aman* and *boro* Paddy Due to Fertiliser Treatments. (*Source :* M A Islam (1961) *Fertiliser Trials on Paddy in Farmers' Fields in East Pakistan* International Rice Commission Newsletter, Vol (2) pp 10-19).

doses are 40 Kg N + 40 Kg P_2O_5 + 40 Kg K_2O per hectare in the form of Urea + superphosphate (or bone meal) + muriate of potash.

The work of Wahhab and Muhammad (1955) in West Pakistan has shown that with 40 lbs. N per acre, wheat yields can be increased from 20—50 per cent. The response to phosphate has been found to be small but the combined application of N + P fertilisers was higher than with N alone. The soils of the rainfed area, particularly those of Rawalpindi, have been shown to be deficient in phosphorus ; 50 lb. P_2O_5 at sowing plus 40 lb N with the first shower gave the highest response [85% increase over control (no fertiliser)]. Ammonium phosphate gave higher yields than ammonium sulphate with irrigated wheat on cultivators' fields.

Cotton has also been found to respond to phosphate in combination with nitrogen but the higher response due to additional phosphate was not always economic.

Berseem (Egyptian clover) responsed to phosphate up to 100 lb. P_2O_5 per acre in Lyallpur, Montgomery, and Multan areas.

Taiwan : Form 1930 to 1942, 549 field experiments on rice were conducted at 118 localities on the whole island of Taiwan. In these experiments ammonium sulphate, superphosphate and potassium sulphate were used as fertilisers. The response of rice to N P K fertilisers is shown in Table 16.10.

TABLE 16.10

AVERAGE RESPONSE OF RICE TO N P K FERTILISERS IN TAIWAN, 1930—1942

Elements applied (Kg/ha) ($N+P_2O_5+K_2O$)**	First Crop of Rice			Second Crop of Rice		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
	(Kilograms of Paddy per Hectare)*					
0	2,848	3,512	3,632	2,578	2,968	2,985
	Increase in yield over control					
40	443	156	854	309	113	109
80	871	207	87	558	168	151
120	1041	226	91	737	213	161
160	1075	—	—	795	—	—

* *Note :* Yields are in terms of paddy (rough rice).

Source : H. D. Tseng. *Fertilisers and Manures on Rice in Taiwan.* Soils and Fertiliser uses in Taiwan. Chinese-American Joint Commission on Rural Reconstruction Plant Industry Series No. 20. 1961

** Each nutrient was added in equal amounts ; for example, 40 lbs. N+40 lbs. P_2O_5+40 lbs. K_2O.

In 1953 and 1955, 173 NPK fertilizer experiments of rice with $3 \times 3 \times 3$ confounding factorial design were carried out at various localities of Taiwan. Ammonium sulphate, superphosphate, and potassium chloride were used as fertilisers. The response of rice to NPK fertilisers is shown in Table 16.11.

TABLE 16.11

AVERAGE RESPONSE OF RICE TO NPK FERTILISERS IN TAIWAN, 1953 AND 1955

Element applied Kg/ha ($N+P_2O_5+K_2O$)	First Crop of Rice N	P_2O_5	K_2O	Second Crop of Rice N	P_2O_5	K_2O
		(Kilograms per hectare)*				
0	2,579	2,992	3,254	2,603	2,985	2993
		Increase in yield over control				
60**	879	126	54	542	111	112
120	1280	169	74	968	174	139

* *Note :* Yields are in terms of paddy (rough rice).

Source : H. D. Tseng. *Fertilisers and Manures on Rice in Taiwan.* Soils and Fertiliser Uses in Taiwan. Chinese-American Joint Commission on Rural Reconstruction Plant Industry Series No. 20. (1961)

** Each nutrient was added in equal amounts : for example, 60 lbs. N + 60 lbs. P_2O_5 + 60 lbs. K_2O.

The results indicate that the soils of Taiwan are deficient in nitrogen, followed by phosphorus. The potassium deficiency is the least. The response of rice to nitrogen is more significant in the first crop than in the second crop, while the response of rice to phosphorus shows about the same degree for the two crops ; and that the response to potash is less in the first crop than in the second crop.

Application of nitrogen fertiliser will increase the yield of rice grain by 34 to 50 per cent for the first crop and 21 to 33 per cent for the second crop. Application of phosphate or potassium will cause an increase of yield by 2 to 6 per cent. The response of rice to phosphate and potassium was higher on red soils than on other soil groups. On the basis of fertiliser trials, the recommendations have been formulated for the various regions. The general fertiliser recommendation for rice is 80 to 100 Kg N plus 40-60 Kg P_2O_5 plus 40-60 Kg K_2O per hectare. It has, however, been noticed that farmers actually use more nitrogen and less phosphate and potassium than the recommended doses.

Thailand : Farmers in Thailand seldom used fertilisers for rice soils but in recent years efforts have been made to increase the productivity of rice soils by use of fertilisers. Simple fertiliser trials on rice have been conducted

in cultivators' fields. In 1958-59 and 1959-60, seven treatments were used N, P, K, NP,NK.PK, and NPK. Each nutrient used was applied at the rate of 75 kg. per hectare in the first year and 37.5 kg./ha. in the second year.

The results indicate that the single application of each nutrient gave average increases in paddy yield of about 28 per cent for nitrogen, 25 per cent for phosphorus and only 15 per cent for potassium. The combination of N and P gave noticeable increases in yields—about 53 per cent over the check. The results indicate that rice soils in Thailand in general seem to be deficient mostly in nitrogen and phosphorus. In these trials, differences in response due to locality were also significant, being lower in the Northern region and higher in the North Eastern region.

From 1960-62 the experiments were conducted to determine the nitrogen needs in different regions of Thailand in order to obtain the most economical return. On the basis of these results, the following recommendations have been made for Thailand.

(a) Northern Region—50 Kg N, 25 Kg P_2O_5, and 25.0 Kg K_2O per hectare. Expected yield increase 30%.

(b) Central Region—50 Kg N and 25 Kg P_2O_5 per hectare. Expected yield increase 50%.

(c) Northeastern Region—37.5 Kg N, 25 Kg P_2O_5 and 25 Kg. K_2O per hectare. Expected yield increase 75-80%.

(d) Southern Region—37.5 Kg N and 25 Kg P_2O_5 per hectare. Expected yield increase 50%.

Korea : Experiments conducted to find the response of rice to nitrogen, phosphorus, and potassium in different locations in Korea in 1959-60, reveal the following results. (Table 16.12).

TABLE 16.12

AVERAGE YIELDS OF ROUGH RICE OBTAINED FROM NPK FERTILISERS IN KOREA, 1959-60

Fertiliser Applied Kg per Tanbo	Suwan 1959	Inchon 1960	Pyongtaek 1960	Iri 1960
Nitrogen (N)	(Yield of Rough Rice in Kg/Tanbo)			
0	313.8	404.6	389.6	383.8
4	342.4	443.5	440 6	454.2
8	341 6	460.9	414.5	475.8
* L.S D. 5%	—	20.8	15.2	18.2
1%	—	27.9	20.2	24.3
Phosphate (P_2O_5)				
0	323.5	429.6	400.4	441 6
4	334.7	442.0	393.9	435.5
8	340.6	434.4	414.5	436.2
L.S.D. 5%	—	N.S. **	N.S.	N.S.

TABLE 16.12 *(Contd.)*

AVERAGE YIELDS OF ROUGH RICE OBTAINED FROM NPK FERTILISERS IN KOREA, 1959-60

Fertiliser Applied kg. per Tanbo	Suwan 1959	Inchon 1960	Pyongtack 1960	Iri 1960
Potassium (K_2O)		(Yield of Rough Rice in kg/Tanbo)		
0	336.5	423.4	407.6	432.5
4	324.2	449.6	409.3	436.9
8	337.4	437.5	391.9	443.8
L.S.D. 5%	—	N.S.	N.S.	N.S.

* L.S.D. means least significant difference.

** N.S. means that the yields were not significant over the control (zero fertiliser).

Source Wang Keun Oh. *Fertiliser Response on Rice in Korea.* International Rice Commission Newsletter, Vol. XI (3), 19-21, 1962.

No response to potassium was obtained. Small response from nitrogen and phosphorus applications was noted at Suwon in 1959 on soils derived from fluvial deposits. In Pyongtack and Iri soils derived from marine deposits, no response to phosphorus and potassium was obtained but a a large response to nitrogen was noticed. In Inchon area, large responses to nitrogen and slight responses to phosphorus and potassium have been noted.

The chemical analysis of soils at the four locations where the experiments were conducted is given in Table 16.13. Available P_2O_5 was determined by Lancaster's method. The pH of the soil was acid and it is therefore not surprising that phosphate response was poor. Liming of such soils is indicated. Response of phosphate and potassium would probably increase with liming, since the available P_2O_5 and K status is low to medium.

TABLE 16.13

CHEMICAL ANALYSIS OF SOIL SAMPLES FROM DIFFERENT LOCATIONS IN KOREA

Region	No. of Samples	pH	Available P_2O_5 (ppm)	Exchangeable K (ppm)
Suwon	15	5.1—5.7	15—22	30—60
Inchon	12	5.5—6.7	12—20	120—200
Pyongtack	12	4.9—5.3	17—50	90—170
Iri	12	4.8—5.3	16—30	27—80

Source : Wang Keun Oh *Fertiliser Response of Rice in Korea.* International Rice Commission Newsletter, Vol. XI (3) 19-21, 1962.

Burma : Simple fertiliser experiments on paddy in farmers' fields were conducted from 1957-58 to 1959-60. The total number of trials was 604. Fifty-five experiments were conducted under irrigated tracts while the rest

were done in rainfed areas. Table 16.14 shows the condensed results of three years.

TABLE 16.14

RESPONSE OF PADDY TO FERTILISERS IN SIMPLE FERTILISER TRIALS ON CULTIVATORS' FIELDS ON ALLUVIAL SOILS IN BURMA

Year		Control	Increase in Yield over Control					
			N_1	P_1	K_1	N_1P_1	$N_1P_1K_1$	N_2
		(Kilograms of paddy per hectare)						
1957-58	Yield	2057	193	0	73	193	266	194
	Relative Yield	100	109	100	104	109	113	109
1958-59	Yield	2156	188	123	84	311	395	315
	Relative Yield	100	109	106	104	114	118	115
1959-60	Yield	2047	227	207	115	434	549	391
	Relative Yield	100	111	110	106	121	127	112
Average of 3 years		2087	203	133	67	336	403	300
	Relative Yield	100	110	106	103	116	119	114

Notes : (1) N_1=22.4 Kg N per hectare P_1=33.6 Kg P_2O_5 per hectare. K_1=44.8 Kg K_2O per hectare. N_2=44.8 Kg N per hectare.

(2) There is no treatment as P_1 and K_1. The increase yield in Kg/ha shown in table is calculated from appropriate treatments, i.e., to obtain P_1, N_1 is subtracted from N_1P_1 and to obtain K_1, N_1P_1 is substracted from $N_1P_1K_1$.

(3) The number of experiments in 1957-58 was 110; in 1958-59 it was 298; and in 1959-60 it was 196.

Source : U Shein Mgand Khin Win. *Fertiliser Trials on Paddy on Farmers' Fields in Burma.* International Rice Commission Newsletter XI (3) 23-28 (1962).

Results have brought out the need and efficiency of combined application of all three major nutrients. NPK treatment is superior to NP in all three years. The response to nitrogen is highest, followed in order by phosphorus and potassium.

NP application was equal or superior to NPK in certain districts of Burma such as Hanthawaddy, Prome, Tharawaddy, Descin, Thaton, Katha, Sandoway and Mindu. In the other 25 districts, NPK was superior.

Despite the higher response of NPK over NP treatment, economic and other considerations have limited the use of potassium fertilisers. The present recommendation is a combined application of nitrogen and phosphorus fertilisers.

A high actual and visual response to nitrogen applications has encouraged farmers to use only nitrogen fertilisers, but the increased yields could not be sustained without P and K, and yields declined. The decline in yield was observed on calcareous as well as on acid soils. The application of phosphate has reduced the depressive effect of nitrogen alone and the combined application of nitrogen and phosphorus forms the present recommendation of the Burmese Department of Agriculture.

Philippines : Usually about 150 kilos of 12-24-12 fertiliser are applied per hectare on rice during the last harrowing or levelling of the field just before transplanting. This is followed by the application of ammonium sulphate fertiliser before the booting stage of the rice plant. In some cases, the fertiliser is applied only once, 2 or 3 weeks after transplanting. (See Figure 16.12.)

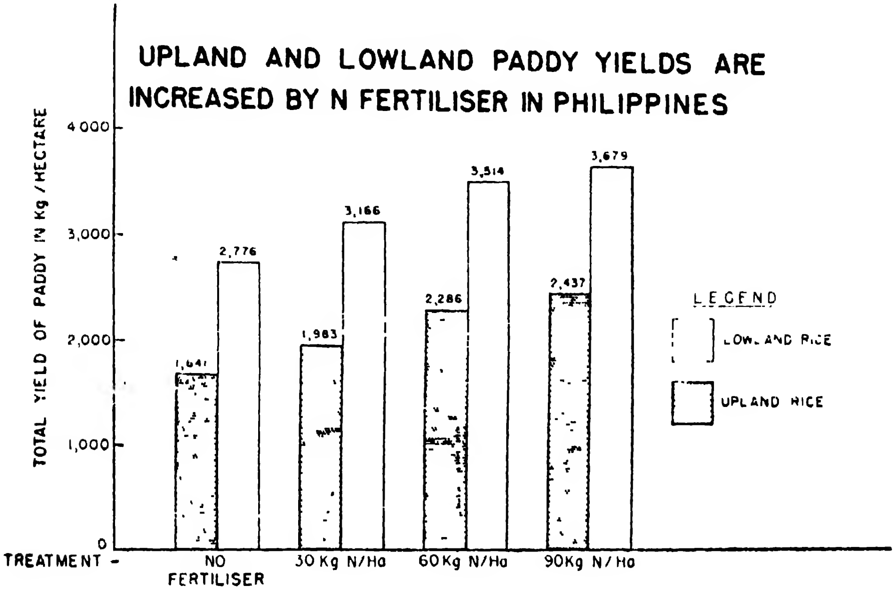


Fig. 16.12 On farmers' lowland rice fields in Phillippines, 19 fields (65%) gave a positive response to applications as high as 90 kilograms of N per hectare, 7 24%) of the fields gave no response, and 3 fieds (11%, gave a negative response. The farmers' varieties of rice were used On farmers' upland rice fields, 13 (72%) gave a positive response to applications of 30, 60, 90 kilograms of N per hectare, 2(11%) did not give a response, and 3(17%) showed a decrease in yield. Neither phosphorus nor potassium fertilisers gave a significant increases in yield. (*Source* : Galvez, N.L., and Cruz, T.C. *Rice Fertilizer Experiments in the Philippines*, Dept. of Soils, College of Agriculture and Central Experiment Station, Los Banos, Philippines. Mimeographed. 1957)

Indonesia : Java has 3.5 million hectares of lowland rice. Approximately 700,000 hectares respond well to phosphorus at 1 quintal/ha, giving an average yield increase of approximately 50 per cent, i.e., 500 to 1000 Kg/ha. Approximately 1 million hectares respond to nitrogen in the form of green manure or ammonium sulphate.

4. INTERACTION OF CROP VARIETIES AND FERTILISERS

Variety-fertiliser interaction for rice has been reported by workers in several countries. Experiments have been conducted on a systematic scale since

1951 through the efforts of International Rice Commission of FAO. The results of fundamental importance have been reported, which should help in breeding varieties which would respond to a high level of fertilisers.

The most striking demonstration of a variety-fertiliser interaction has been reported for rice from Punjab, India. In a trial with coarse-grained strain, *349 Jhona*, and the fine-grained *370 Basmati*, the former gave in unfertilised plots a yield over double that of *370 Basmati*. At 45 Kg. N per hectare, *349 Jhona* gave the highest yield (59.3 per cent increase over unfertilised plot) while at 90 Kg. N per hectare *370 Basmati* gave the highest response (99.9 per cent increase over the unfertilised plot) and out-yielded *349 Jhona*, the yield of which was highest with 45 Kg, N per hectare and declined with heavier application of nitrogen. Thus the optimum dose for the two varieties is 45 and 90 Kg. N per hectare for *349 Jhona* and *370 Basmati* respectively.

At Aduthurai, Madras, paddy variety Adt-20 showed a higher response to application of 45 Kg. P_2O_5 per hectare than the local variety Adt-3.

In another trial at Karnal, Punjab, India, paddy variety *N.P. 130* (a fine variety) produced a larger response to nitrogen than *Jhona 349*. At 22.5 Kg. N per hectare both the varieties gave an increase of 584 lbs. per acre. When the nitrogen dose was increased to 45 Kg. N per hectare, *N.P.130* gave a further response of 186 lbs. per acre as against 56 lbs. by *Jhona 349*.

In rice trials at Bagwai, Madhya Pradesh, India, in the absence of nitrogen fertiliser, no difference in yield was obtained for 3 varieties, *Langi* (local). *T-21*, and *Bankura-1*. When nitrogen was applied at 22.5 Kg. per hectare, *T-21* proved superior, with no difference between *Langi* and *Bankura-1*. When nitrogen application was raised to 45 Kg. per hectare, *T-21*, continued to give the highest yield but the response with *Bankura-1* increased and both improved strains were superior to the local variety. Similarly both improved varieties gave a higher response to phosphate at both levels (22.5 and 45 Kg. per hectare) as compared to the local variety, which was also responsive to phosphate application.

In Viet Nam, rice trials at six centres with 20 varieties revealed striking and significant fertiliser-varietal effects at all the centres. The varieties × fertiliser interaction, however, was significant at one centre only, namely, Cholon. The variety *Doe Phung Lun* showed the highest fertiliser response and *Ve Vang* the lowest.

In Pakistan, though the rice variety × fertiliser interaction has not been found to be significant the *Dharial* variety possessed the highest fertiliser response. *Hashikalmi* had, however, the highest average yield.

Pakistan and Philippines have not reported significant variety × nitrogen intreractions. The results from these two countries indicate a negative effect on yield when nitrogen is used alone.

There is enough evidence from Ceylon and India that the japonica varieties of rice under tropical conditions gave higher fertiliser responses. The performance of japonica × indica hybrids reported from Australia is of particular interest. Two selections, *G 15-16* and *G 16-56* showed the virtues of high fertilisation, high grain-to-straw ratio and lodging resistance. Significant variety × fertiliser interaction of rice has also been reported from Thailand.

The differences between high-and low-response varieties in their capacity to absorb and assimilate nitrogen have been demonstrated. Low-response varieties possess a high initial rate of nitrogen absorption accompanied by a low rate of nitrogen assimilation. The rapid development of a high rate of soluble nitrogen to protein nitrogen restricted further nitrogen absorption and led to nitrogen starvation in later stages of crop growth. Thus, at a particular level of nitrogen, the interaction between varieties and time of nitrogen application is implicit in the above finding. Low-response varieties prefer nitrogen applications as late as is practicable.

5. TIME OF FERTILISER APPLICATION

To obtain the most efficient use of fertilisers, it is necessary to apply the fertilisers in accordance with the needs of the plants at different stages of

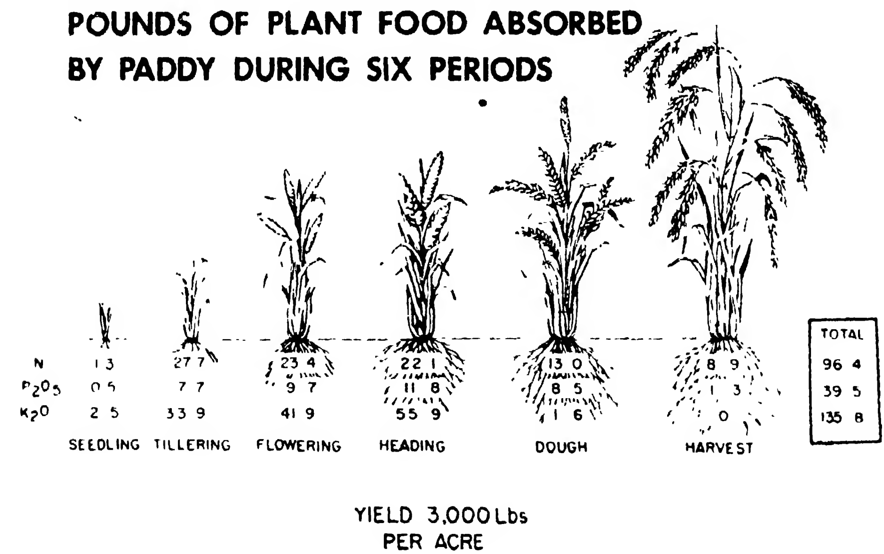


Fig. 16.13 Pounds of Plant Nutrients (Food) Absorbed by Paddy during Different Stages of Growth.

development. The uptake and utilization of nitrogen in particular during various stages of development is different. The result of such experiments with paddy by Japanese workers is illustrated in Figure 16.13.

Experiments on time of application of fertilisers on paddy at the Central Rice Research Institute, Cuttack, Orissa, India, show that fractional application of ammonium sulphate to supply 40 lbs. N per acre (45 Kg. N per hectare) in three doses, viz., at planting, one month after planting, and at the flowering initiation, gave an increased yield of 37 to 50 per cent, while the application of the entire quantity in one dose gave an increase of only 27 per cent. The time of split dressing of the fertilisers should coincide with (1) the active vegetative growth, (2) tillering in the early stages and (3) the flowering initiation.

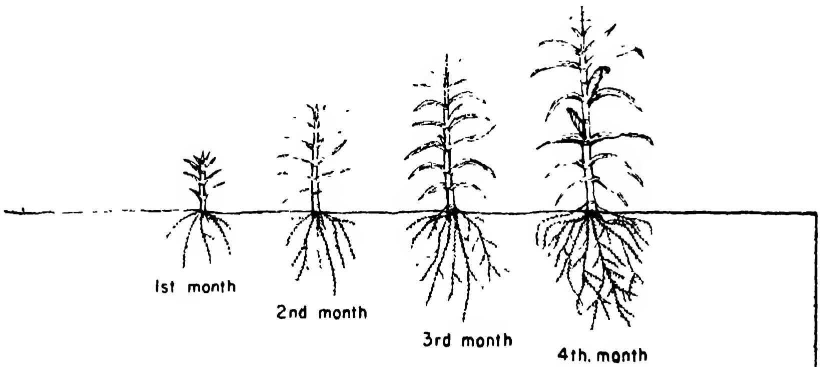
Similar results have been reported by a number of other workers in India and Philippines. Several States in India recommend split application of nitrogen fertiliser for rice, half at the time of transplanting and half 1½ months after transplanting (30 to 35 days before heading). This practice is known to give larger response than single application at the time of transplanting especially on long-duration varieties.

In Ceylon, it was found that 68 Kg. N per hectare as ammonium sulphate applied in a single dose three weeks after sowing. gave the highest yield of rice in an experiment in which 23, 45, and 68 Kg. N per hectare were applied at three times : at sowing, three weeks after sowing, and six weeks after sowing.

The work by Reyes, et. al., conducted at Laguna, Philippines, with lowland rice indicates that marked accumulation of nitrogen occurred at booting and towards maturity, while the phosphorus and potassium uptake of plants was continuous throughout the different stages of growth. Results have shown that in considering nitrogen fertilisation of lowland rice a basal application of nitrogen with additional nitrogen applied at later stage of growth, such as the booting stage, is desirable in order to meet adequately the nitrogen needs of the plants. The phosphorus and potassium should be supplied prior to or at the time of transplanting.

The results with other crops have been reported. There are indications that split application of nitrogen may prove beneficial for wheat and barley. For irrigated wheat, split application of nitrogen has been recommended by several States in India. Sugarcane, cotton, potato, maize, and banana receive top dressing of nitrogen fertiliser besides the application at sowing time. (See Figure 16.14.)

PLANT FOOD ELEMENTS ABSORBED BY AN ACRE OF MAIZE (CORN) DURING MONTHLY PERIODS OF GROWTH



Plant food elements absorbed (Pounds and percentage of total)

					Total Lbs
N	5 (3%)	55 (38%)	69 (48%)	16 (11%)	145
P_2C_5	1 (1%)	19 (27%)	33 (47%)	18 (25%)	71
K_2O	6 (4%)	92 (65%)	43 (31%)	-20 (-14%)	141

Fig. 16.14 Absorption of N, P_2O_5, and K_2O by Maize at monthly intervals. (*Source : Ohio State University, U.S.A.*)

6. FERTILISER PLACEMENT

The usual method of applying ammonium sulphate and other nitrogen fertilisers to crops is by broadcasting and/or top-dressing. These methods have generally been found useful because the ammonium is absorbed by the exchange complex and dangers of loss due to leaching are small. However, after nitrification, the nitrate formed is soluble and is liable to be lost by leaching. This method of application of nitrogen fertilisers in waterlogged rice soils is liable to give less response. Considerable amount of nitrogen applied is lost through denitrification taking place in the soil. Recent research studies in Ceylon and other countries have shown that sub-surface application of ammonium sulphate is more beneficial than the customary surface application for paddy rice. The efficiency of ammonium sulphate can be considerably increased by placement at a depth of 2 to 4 inches. The advantage of sub-surface application of ammonium sulphate to paddy soils is illustrated in Figure 16.15.

Sub-surface application is done in different ways, depending upon the prevailing soil and water conditions. In dry soils, ammonium sulphate can

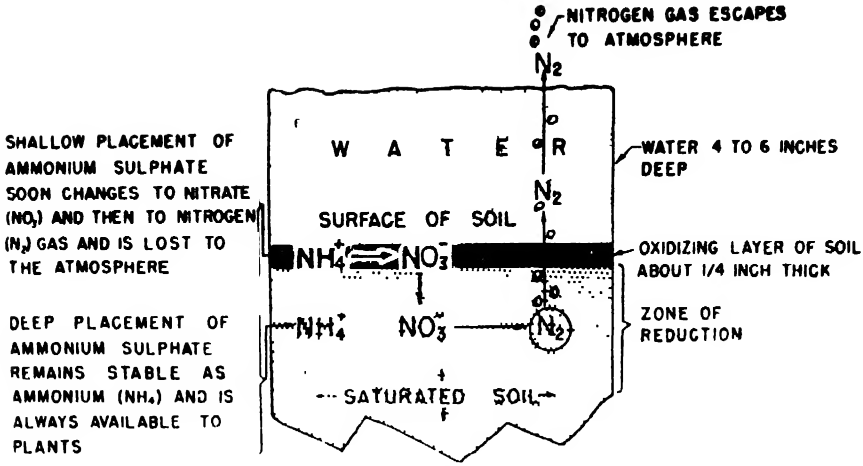


Fig. 16.15 Effect of placement of ammonium sulphate on its stability in paddy soil

be applied two or three inches deep in the plough furrow immediately before letting in water for the puddling, while in wet soils, the fertilisers can be mixed with the soil at the time of weeding. (See Figure 16.16.)

Fig. 16.16 A **desi** plough that was adapted by a farmer near Jabalpur, Madhya Pradesh, India, for placing fertiliser about 2 inches to one side and 2 inches below the seed. The fertiliser goes down the front spout and the seed down the back spout. (*Courtesy Frank Shuman*)

Soluble phosphate fertilisers such as superphosphate become largely unavailable upon reaction with soil for long periods of time. Improved methods are necessary to increase the fraction of phosphate that becomes available to plants, i.e., to minimise fixation because of intimate contact with the soil. Placement of phosphate fertiliser in concentrated bands has increased the response to phosphate application and increased profits to the farmer. A large number of Model Agronomic Trials have been in progress in various parts of India. The experiments have shown that under rainfed conditions, the response of wheat to band place-

ment or placement 2 inches below the seed gives a higher response than broadcast application. Experiments with paddy in India have so far not provided conclusive evidence about the superiority of placement. The results have been contradictory at different centres but recent experiments have demonstrated its advantage. The difference in response of wheat and paddy could be due to the higher moisture status in paddy soils which tends to increase phosphate availability. Higher response of paddy than wheat to phosphate application can also be explained on the same principle. It is considered that when suitable implements for placement of fertilisers have been devised, better response to placement of phosphate application may be expected. One of the first successful models in India to place fertiliser in a continuous band to one side of and below the seed is shown in Figure 16.17

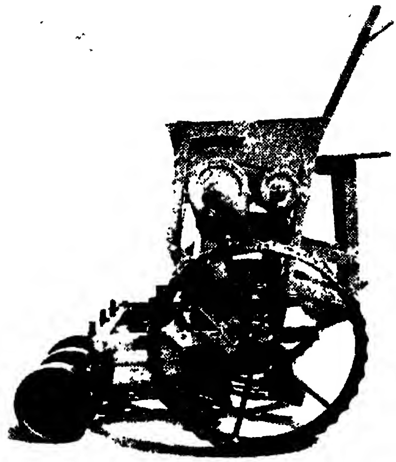


Fig. 16.17 A fertiliser and seed drill that has recently been developed in India. The fertiliser comes down front spout and the seed down the rear spout. The fertiliser is placed about 2 inches to one side and 2 inches below seed level. (*Courtesy . Swastik Mfg Co., Secunderabad, Andhra Pradesh, India*).

7. CHOICE OF FERTILISERS

Experiments on the relative merits of different nitrogen fertilisers have been in progress in different parts of India. The response has varied from place to place. The present results indicate that for paddy, ammonium sulphate is slightly superior and urea is a close second ; nitrate fertilisers are less effective than ammonium sulphate and urea, due to prevailing anaerobic conditions. Urea is however, a slightly superior fertiliser for paddy on laterite and mixed red and black soils of Madhya Pradesh. The slight superiority of ammonium sulphate over urea for paddy has been proved in greenhouse trials at IARI, New Delhi.* The reasons ascribed are higher

*J. Venkoteswarlu *Availability, Distribution and Transformations of Sulphur in Selected Indian Soils, with Special Reference to Rice (Studies with S^{35})* Ph. D. thesis, Division of Soil Science & Agricultural Chemistry, IARI, New Delhi, 1963.

Fig. 16.18 Anhydrous ammonia was first tried in India in the field in 1954-55 in Mysore State, on rice and sugarcane, in comparison with ammonium sulphate. Thirty pounds of N from each source was equally effective *(Courtesy S.V. Govinda Rajan)*

availability of manganese and sulphur with the use of ammonium sulphate as compared to urea. Since urea is cheaper per kilogram of nitrogen, the net profit on the investment to the cultivator would be about the same.

For wheat under irrigated conditions, urea, ammonium sulphate, and ammonium nitrate have proved equally effective at 20 and 40 lb. nitrogen per acre, while under rainfed conditions, ammonium sulphate has proved slightly superior to urea. For sugarcane, urea and ammonium sulphate are equally effective. Anhydrous ammonia was tried in India on rice and sugarcane and was found as effective as ammonium sulphate (Figure16.18).

Among phosphate fertilisers, superphosphate has proved to be most effective fertiliser due to its higher availability. Rock phosphate and bone meal are effective only in acid soils where soluble phosphate in superphosphate is quickly made unavailable. Ammonium phosphate is effective for leguminous crops like groundnut where only a small amount of nitrogen is needed as starter. In recent experiments, dicalcium phosphate has given promising results in higher doses (1000 lb. P_2O_5), and with leguminous crops may prove equal in efficiency to superphosphate.

In Malaysia, a comparison of insoluble and solube forms of phosphate fertilisers has been made. The cost per unit of soluble form of P_2O_5 is nearly three times that of the insoluble form. It was found that in a three-season trial, superphosphate was only slightly superior to equivalent Christmas Island rock phosphate or bat guano. The response was similar in simple fertiliser trials on farmers' fields. Rock phosphate from Christmas Island was found superior to rock phosphate from North Africa; also the former is cheaper and of higher analysis. Christmas Island phosphate is 37% total P_2O_5 ; African phosphate is 26 total P_2O_5.

8. FERTILISER AND SOIL MOISTURE EFFICIENCY

India had 47 million acres of irrigated area in 1947. Since independence, with the opening of multipurpose irrigation and power projects, 10 million more acres have been brought under irrigation. Even more acreage is likely under small and big irrigation projects. Provision of irrigation facilities has been the easiest and assured method of increasing food production but this irrigation potential has not been fully utilized. The efficient use of water envisages that the soil should provide ample nutrition for the crop. On many soils in India, however, the principal limiting factor in crop production is low fertility. It is only under circumstances where both soil fertility and water management are adequate, can maximum yields be obtained.

Fertiliser response is much higher with adequate irrigation, and the return on investment on irrigation is better and more fully compensated when the nutrient status of the soil is raised by the addition of fertilisers. Leather quoted by Raheja, Donahue and Satyanarayana (1961) has shown manuring decreased the transpiration ratio of a number of crops like *arhar*, *guar*, barley, oats, gram, maize, and wheat. The transpiration ratio in fertilised wheat is only two thirds of that for unfertilised wheat. The interaction between nitrogen levels and water duty has been found to be significant in the case of sugarcane.

The combined use of fertilisers and irrigation water give better response, and thus an economy of water per unit of the crop produced. Similar results indicating greater efficiency of water use have been reported by several workers. (Figure 16.19)

Research in Arizona (Southwestern USA) on the irrigation of lucerne (alfalfa) has shown that adequate phosphate fertilisation reduced the water requirement from 14.2 to 7.8 acre-inches per ton of hay (dry fodder) produced. In Texas (Southwestern USA) nitrogen fertilisers alone increased the yield of maize by 280 pounds per acre, while irrigation alone increased it by 560 pounds. The same amounts of nitrogen and irrigation water applied *together* increased the yield of maize by 1,850 pounds. Water and fertiliser together were more than twice as efficient as when each is used separately.

With a uniform and adequate application of all other essential elements, increasing amount of nitrogen fertiliser in Texas increased the yield of Coastal Bermudagrass and decreased the water requirement per ton of hay (dry fodder) produced. With no nitrogen fertiliser the yield of hay was 2.5 tons; with 100 pounds of N per acre the yield was 4.5 tons;

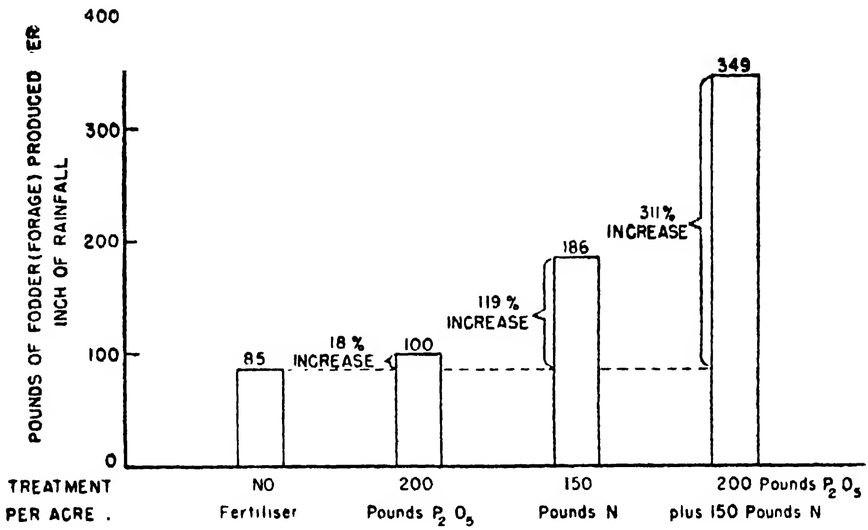


Fig. 16.19 Fertiliser increases water efficiency of range forage .(*Source* *Mckell, C.M. , J. Major, and F.R. Perrier Range Fertilization of Annual Forage Plants Acids use of Available Soil Moisture.* California Agriculture, Vol 15, No 5, 1961.)
Note : Average Annual Rainfall 20 inches.

and with 400 pounds of N it was 8.5 tons. The corresponding water requirements were 17.5, 10.5, and 5.5 inches of water per ton of hay. (See Figure 16.19.)

9. EFFECT OF FERTILISERS ON CHEMICAL COMPOSITION OF CROPS

The chemical composition of berseem clover, cowpeas fodder, and wheat grain and straw as affected by fertiliser treatments in Delhi alluvial soil is given in Table 16.15.

It is clear that phosphate and calcium content of the berseem clover and cowpea fodder, the phosphate content of wheat grain and the N and P_2O_5 content of wheat straw increased with superphosphate and farmyard manure application over the corresponding values in respect to the "no manure—no fertiliser" series.

The analysis of crops from Pusa permanent manurial plots (Bihar, India) has shown that phosphate fertiliser alone and in combination with nitrogen and potassium fertiliser and green manure crops, all significantly

TABLE 16.15

CHEMICAL ANALYSIS OF BERSEEM CLOVER, COWPEA FODDER, AND WHEAT GRAIN AND STRAW AS INFLUENCED BY FERTILISATION

Treatment per acre	Berseem clover 1940-41			Cowpea 1942			Wheat Grain 1943-44		Wheat Straw 1943-44	
	N	P_2O_5	CaO	N	P_2O_5	CaO	N	P_2O_5	N	P_2O_5
	Percentage on dry matter basis									
No manure, no fertiliser	3.8	0.38	3.06	2.24	0.32	2.86	2.15	0.68	0.44	0.07
Superphosphate at 132 lb. P_2O_5	3.84	0.82	3.56	2.75	0.83	3.47	2.08	1.00	0.53	0.16
Farm yard Manure at 80 lbs. N	3.72	0.83	3.70	2.32	0.75	2.87	2.16	1.15	0.69	0.22

Source : S. Sen and W. V. B. Sundera Rao. *Phosphate Fertilization of Legumes*. Indian Council of Agricultural Research, I.C.A.R. Review Series No. 3 (Undated Publication).

increased the phosphate content of wheat grain. Nitrogen alone reduced the phosphate content. The protein content was increased with rape cake, nitrogen, potassium, nitrogen + potassium fertiliser, and green manure crops ; while nitrogen + phosphate, potassium +-phosphate, and NPK fertilisers slightly decreased the protein content of wheat grain.

The increase in the uptake of copper and cobalt in the berseem clover plant due to phosphate fertilisation has been reported by workers at IARI, New Delhi.

Several workers have reported an increase in the ascorbic acid content in response to manganese application to tomato grown on manganese deficient soils. Manganese fertilisation increased the carotene content of leaves of soyabean, corn, wheat, and oats. Results on Pusa permanent manurial crops show an increase in thiamine and riboflavin content of wheat grain following the application of NPK fertilisers. The niacin content of wheat increased due to phosphate and potassium fertilisers and green manure crops.

The deficiency of potassium causes a decrease in the accumulation of simple sugars and amino acid and the net synthesis of complex carbohydrates and proteins. Recent work has shown that potassium or calcium deficiency causes the accumulation of soluble nucleotides in maize seedlings, and the synthesis of ribonucleic acid is reduced.

The effect of different rates of nitrogen on the chemical composition of corn (maize) has been reported by Galvez et. al. (1956) from Laguna,

Philippines. The results show that hybrid 2 and Cuban variety had the highest nitrogen content. The amount of phosphorus increased with both 45 Kg and 90 Kg N per hectare. The amount of phosphorus in the grain showed an increase with 45 Kg and 90 Kg N per hectare but there was no significant difference between the two nitrogen doses. The results are given in Table 16.16.

TABLE 16.16

EFFECTS OF THREE LEVELS OF NITROGEN ON NITROGEN AND PHOSPHORUS CONTENTS OF CORN (MAIZE) GRAIN IN LALAKAY, LOS BANOS, PHILIPPINES

Maize (Corn)	Fertiliser Treatment per Hectare — Composition of Grain: O Kg N		45 Kg N		90 Kg N	
	N	P	N	P	N	P
Hybrid :	(Percentage on Dry matter Basis					
(1) (A105×A106)× (A114×A115)	0.81	0.42	1.49	0.82	1.54	0.85
(2) (A105×A109)× (A113×A114)	1.50	0.29	1.60	0.39	1.98	0.32
(3) (19×112)×(A110×A112)	0.74	0.41	1.36	0.62	1.49	0.61
(4) (193×194)×(A111×A112)	1.15	0.38	1.43	0.77	1.30	0.70
(5) (118×180)×(A112×A114)	1.35	0.35	1.49	0.28	1.83	0.28
Varieties :						
(6) Cuban	1.54	0.30	1.55	0.32	1.90	0.20
(7) Catambay's Cuban	1.32	0.29	1.64	0.40	1.80	0.24
(8) College Yellow	1.40	0.38	1.34	0.74	1.64	0.69

Source : Galvez, N. L., *et. al.* Philippine Agriculturist, University of the Philippines, XL (3) 104-114. 1956

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CHAPTER SEVENTEEN

SOIL FERTILITY EVALUATION

If land be unproductive, and a system of ameliorating is to be attempted, the sure method of obtaining the object is to determine the cause of its sterility, which must necessarily depend upon defect in the constitution of the soil, which may be easily discovered by chemical analysis."

HUMPHREY DAVY, 1813

Soil fertility and soil productivity are often used synonymously but most scientists prefer to make a distinction between the two words. Soil fertility may be defined as the ability of the soil to provide all the essential plant nutrients in available form and in a suitable balance. It is also understood that the soil should be free from any toxic substances. Thus the saline soil could otherwise be fertile but the excess of sodium salts would be toxic to plants. The excess of sodium salts will of course disturb the balance between sodium, calcium, potassium, and other nutrient ions. Soil productivity on the other hand is the ability of the soil to produce crops. Thus soil fertility, good management practices, availability of water supply, and a suitable climate contribute toward soil productivity. Thus the soil can be highly fertile, i.e., it has ready supply of nutrients yet it may be unproductive, say, due to an insufficient water supply. Soil fertility denotes the status of plant nutrients in the soil, while soil productivity connotes the resultant of various factors influencing crop production, both within and beyond the soil.

The continued prosperity and well being of the people of any nation is dependent upon several factors, one of the most important being the level of soil fertility. The soil must always be kept in a fertile condition if high yields are to be produced and people are to prosper. If any essential nutrient is deficient it should be supplied, since any deficient nutrient limits crop yields. Higher and higher crop yields are essential for the feeding of an increasing population. The soil fertility, therefore, should not only be maintained but constantly improved to reap rich harvests. Fertilisers and manures are necessary for maintaining the soil in a high state of fertility and productivity. Before correct fertiliser recommendation can be made, it is important to know the relative level of nutrients and which plant nutrients are deficient in the soil.

I. METHODS OF SOIL FERTILITY EVALUATION

Various methods have been employed to evalute soil fertility to predict the plant requirements and to recommend the proper kinds and amounts of fertilisers or soil amendments. The ideal method to determine soil fertility would be to measure the available plant nutrient content of a soil at a given moment and also to estimate the capacity of a soil to maintain a continuous supply of plant nutrients for a crop until maturity. The various methods to evaluate soil fertility are classified as follows :

I. Chemical Methods
- 1. Soil Analysis
  - (a) Total analysis
  - (b) Tests for available nutrients.
- 2. Plant Analysis
  - (a) Total analysis
  - (b) Plant tissue tests
  - (c) Biochemical methods.

II. Biological Methods
- 1. Use of Higher plants
  - (a) Simple fertiliser trials on cultivators' fields
  - (b) Complex field experiments
  - (c) Methods using plants as nutrient extractants
    - (i) Mitscherlich technique
    - (ii) Neubauer seedling method
  - (d) Use of indicator plants
  - (e) Visual diagnosis
  - (f) Foliar sprays

2. Microbiological Methods
   (a) *Azotobacter* plaque test
   (b) *Aspergillus niger* test
   (c) *Cunninghamel* la plaque method
   (d) Carbondioxide evolution method

2. SOIL ANALYSIS

The first attempts at evaluating soil fertility were made by total analysis from a soil extract with strong acids. It soon became clear that this method gave values too high to predict available plant nutrients. Later weak acids were used as extractants to simulate the ability of plant roots to extract nutrients from the soil. These weak acids gave much better results in evaluating soil fertility.

Dyer's one per cent citric acid method for available phosphorus and potassium was used for many years. This method has limitations, particularly for calcareous soils, since in such soils extra amounts of citric acid would be needed to destroy carbonates.

Various other workers have used different extracting media. The extracting solutions which have been used range from weak acids and salts, such as those used in Michigan (Spurway) tests, through a fairly strong salt solution used by Bray in Illinois, to relatively strong mineral acids such as hydrochloric, nitric, and sulphuric acids in dilute concentrations. Some of the extracting media in use are summarized in Table 17.1.

TABLE 17.1

EXTRACTING MEDIA IN USE WITH DIFFERENT SOIL TESTS

Name of soil test kit	Nutrient	Extracting solution
1. Purdue	Phosphorus	0.4 per cent ammonium molybdate solution in 6.3 per cent hydrochloric acid.
	Potassium	16.5 per cent sodium nitrate, 0.25 per cent cobaltinitrite, and 0.25 per cent acetic acid, adjusted to pH 5.0 with acetic acid.
2. Morgan soil testing system	NO_3, ammoniacal nitrogen, potassium, phosphorus, calcium, magnesium, and aluminium.	10 per cent solution of sodium acetate in 3 per cent acetic acid solution, with pH adjusted to 4.8.
3. Spurway *Simplex* soil testing system	PO_4, K, Ca, and Mg.	0.028 N acetic acid.
4. Truog method	Phosphorus	0.002 N sulphuric acid containing 3 gm. $(NH_4)_2SO_4$ per litre, buffered to pH 3.0
	Potassium	1 N ammonium acetate, pH 6.8
5. Bray method	Phosphorus (P_1)	0.025 N HCl and 0.03 NH_4F

TABLE 17.1 *(Contd.)*

EXTRACTING MEDIA IN USE WITH DIFFERENT SOIL TESTS

Name of soil test kit	Nutrient	Extracting solution
	Phosphorus (P_2)	0.1 N HCl and 0.03 N NH_4F
	Potassium	22% sodium perchlorate, pH 7.0.
6. Olsen method	Phosphorus	0.5 M $NaHCO_3$, pH 8.5
7. A.I.R.I. method, New Delhi	Phosphorus	0.5 M $NaHCO_3$, pH 8.5
	Potassium	1 N ammonium acetate, pH 7.0

Source: Raychaudhuri, S.P. and B.V. Subbiah, *Soil Testing Kits*, ICAR Research Series No. 14, ICAR, New Delhi.

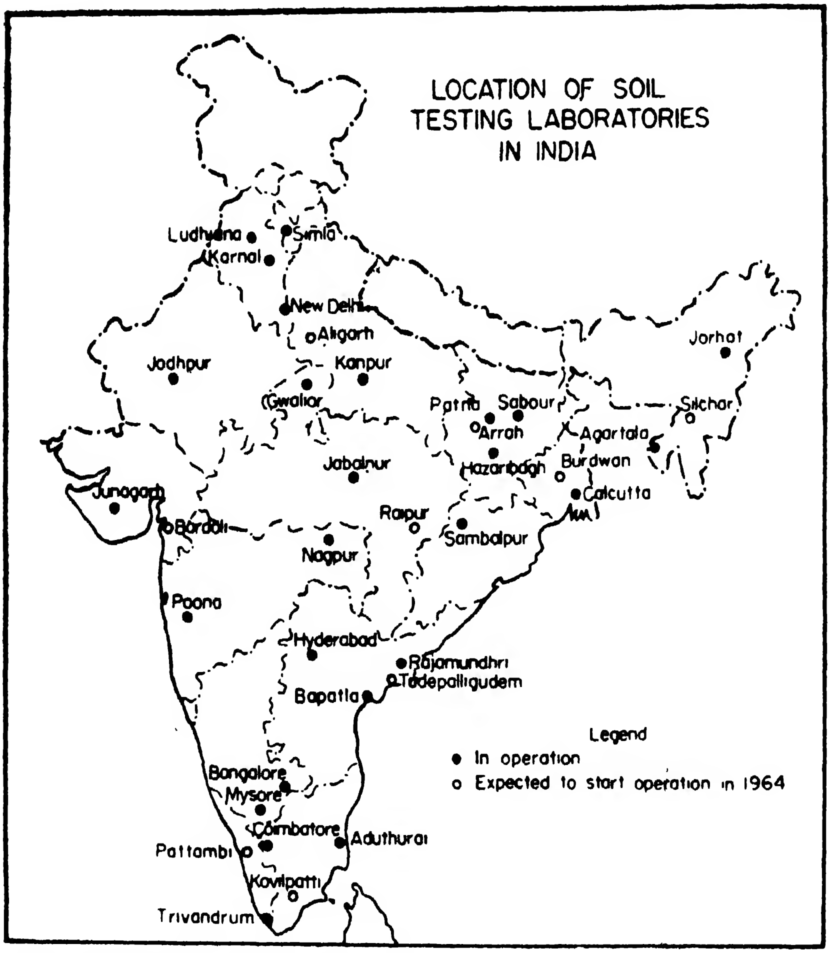

Fig. 17.1 Soil Testing Laboratories in India.

Soil analysis provides a rapid technique to determine plant nutrient deficiencies in soils. There is now considerable interest in India, Pakistan, Philippines, and in other Tropical Asian countries in soil testing as a means to improve the efficiency in the use of fertilisers to maximise crop production.

3. SOIL TESTING SERVICE IN INDIA

Rapid soil tests for nitrogen, phosphate, potassium, pH, organic carbon, and conductivity are being conducted at the Indian Agricultural Research Institute (IARI) New Delhi, and in 23 state soil testing laboratories in India, started in 1955-1956. Every state in India has at least one such laboratory and several states have 2 or more laboratories. The location of soil testing laboratories in India is given in Figure 17.1. These soil testing laboratories analyze free of cost, soil samples received directly from farmers or through agriculture extension workers. (See Figures 17.2 to 17.10.)

Collection of soil sample : Only 1-10 gm. of soil are used for each soil test and unless care has been taken in collecting representative soil samples, all other precautions in analysis and interpretation will have no value. The field should be divided into sampling units on the basis of uniformity of slope, colour, texture, fertiliser treatment management, and cropping

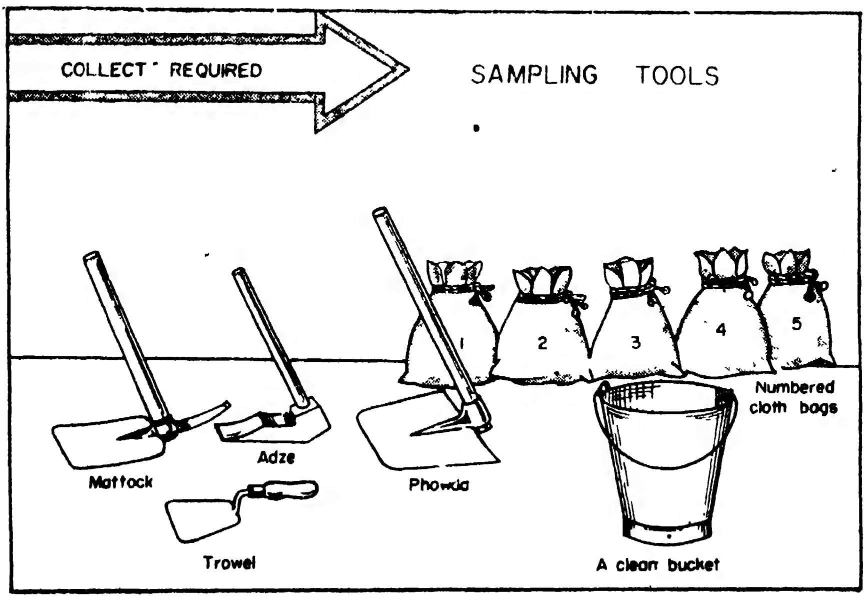

Fig 17.2 The correct soil sampling tool should be selected, depending upon the hardness of the soil and the availability of the tool.

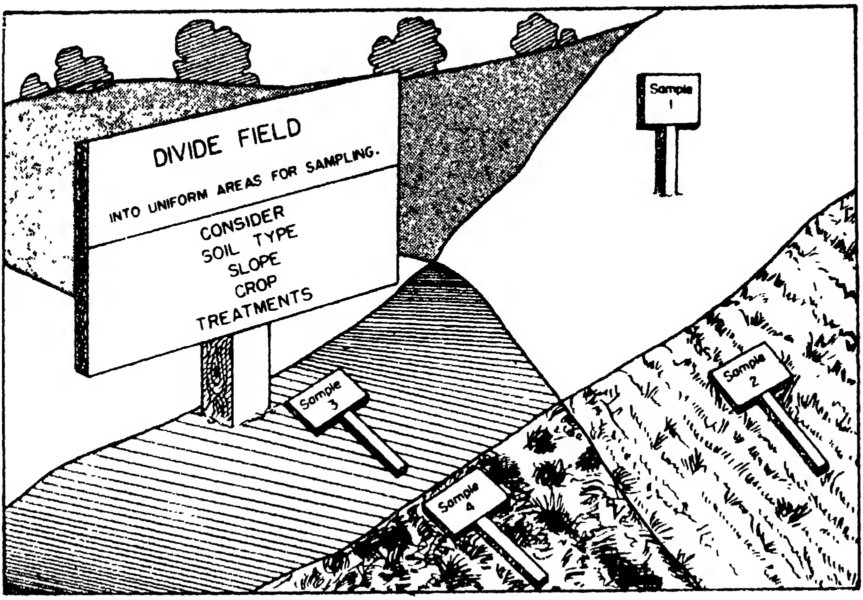

Fig. 17.3 The field should be divided into areas that are uniform as to soil type, slope, cropping system, and past fertiliser treatment. One composite soil sample should be sent from each such fields

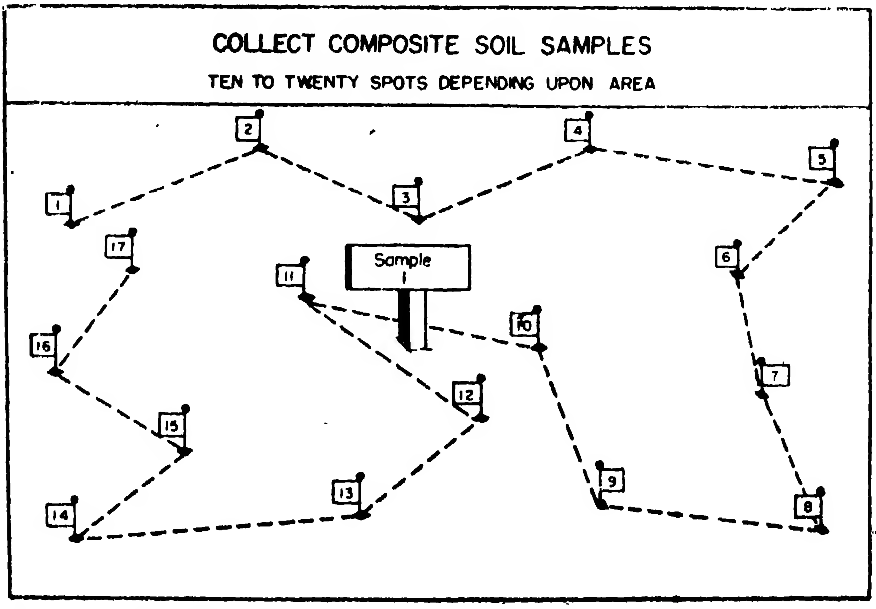

Fig. 17.4 Subsamples from the surface soil should be collected from at least 10 spots in each field

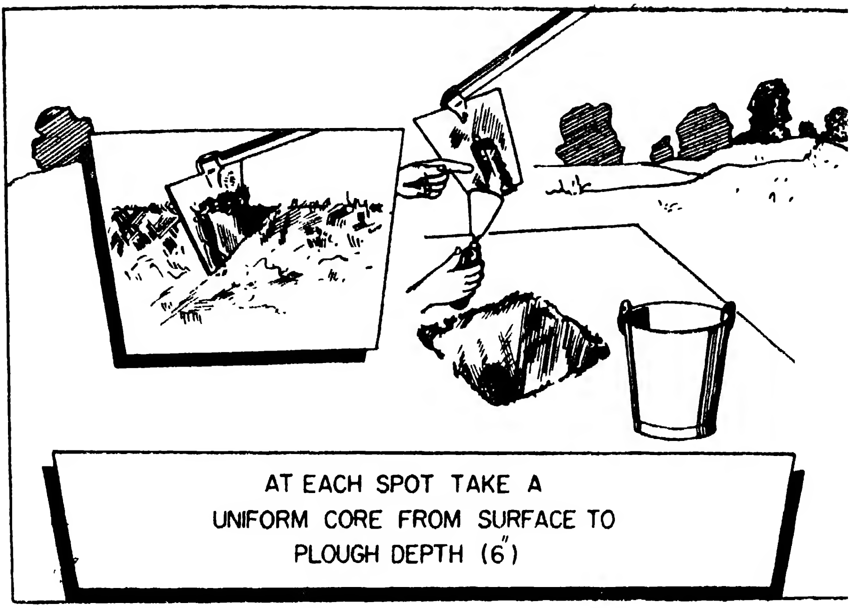

Fig. 17.5 At each of or more than ten spots, a subsample of surface soil should be taken to a depth of 6 inches and placed in a clean bucket.

Fig. 17.6 Mix the subsamples in the bucket and take a one-pound (half kilogram) sample for placing in the bag and sending to the soil testing laboratory.

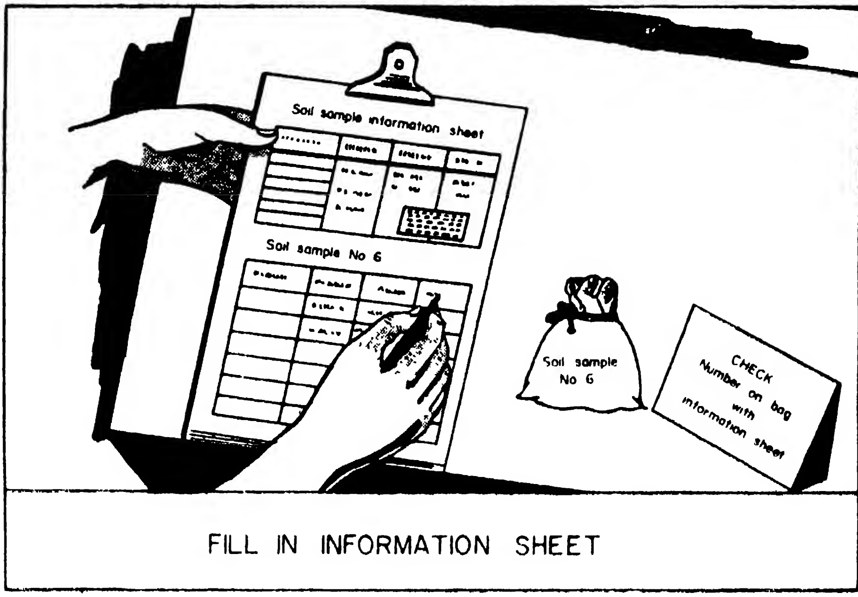

Fig. 17.7 Fill in the information sheet for each soil sample for guidance of the laboratory staff in making the fertiliser recommendation

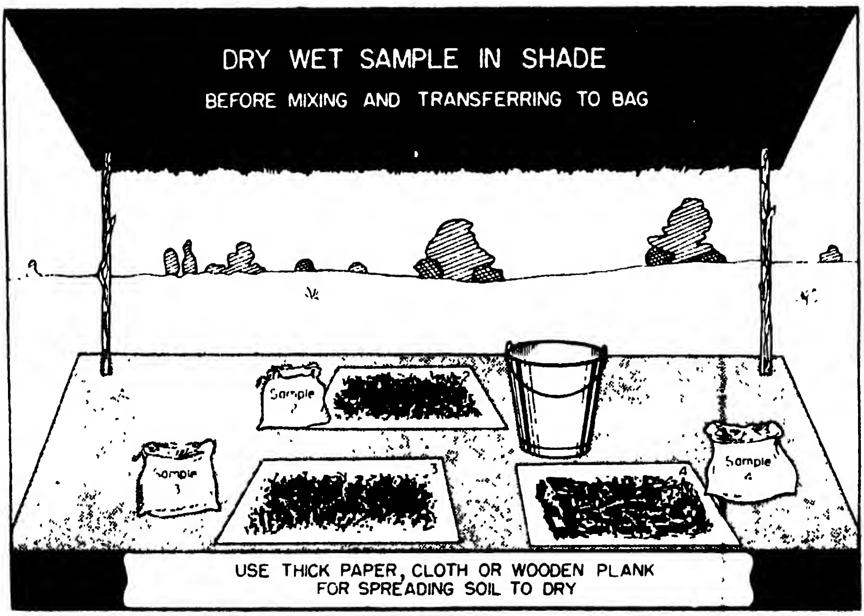

Fig. 17.8 If the soil sample is wet it should be dried in the shade before putting in the bag.

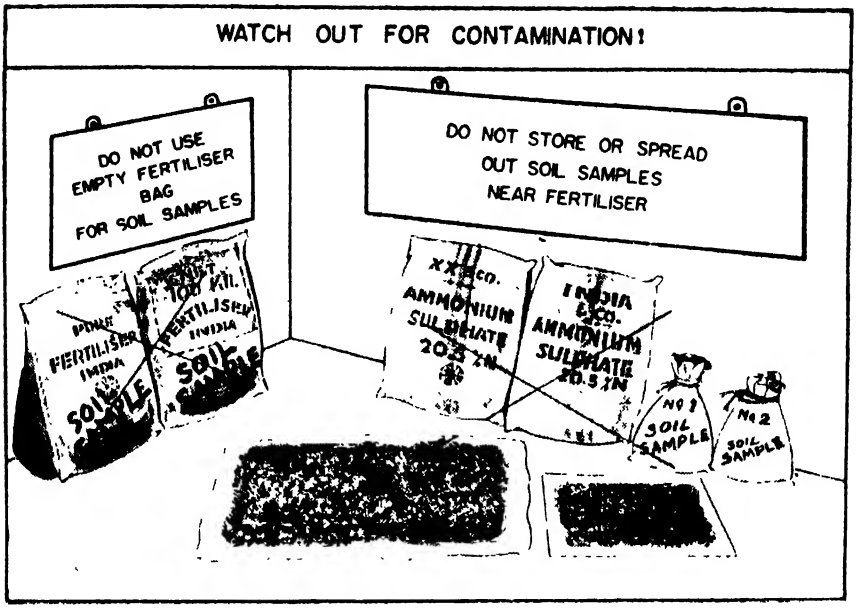

Fig. 17.9 Avoid contamination by keeping soil samples away from stored fertiliser or away from used fertiliser bags.

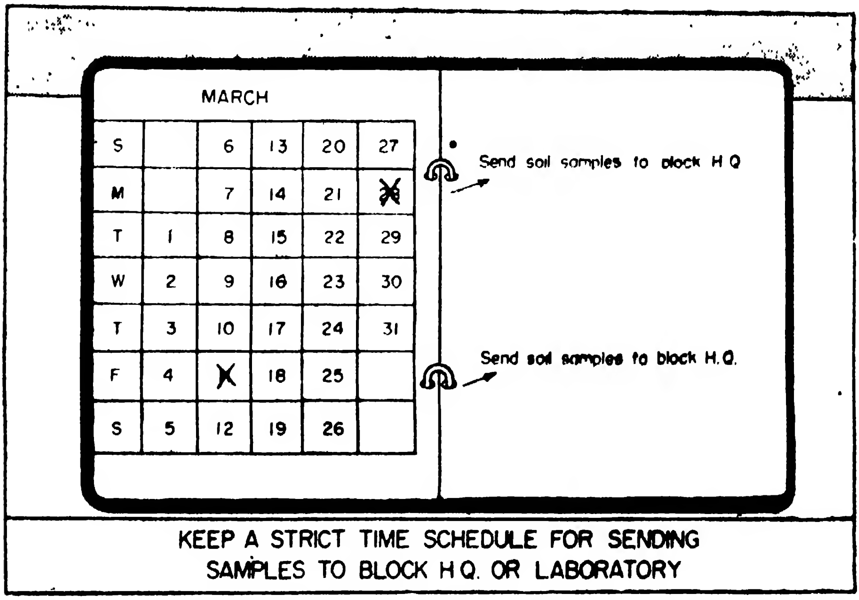

Fig. 17.10 A definite schedule should be agreed upon for sending soil samples to the soil testing laboratory so that the work may progress efficiently

pattern. Separate composite samples should be collected to a depth of six inches from at least 10 well-distributed spots, mixed well and about one pound of the representative sample should be bagged, labeled, and sent to the laboratory.

The correct sampling tool is essential for collection of good soil samples. For a soft, moist soil, the soil tube, *phowda* (spade) *khurpi*, or trowel are quite satisfactory. For harder soils, a screw-type augur, or an adze would be more convenient. Post hole augurs are convenient for sampling very wet areas like paddly fields, or for obtaining samples from the subsoil.

Methods of analysis : Initial work on standardization of analytical methods was done by IARI, New Delhi and these methods, with slight modifications, are being followed by all soil testing laboratories in India.

Available potassium is estimated by the flame photometer, after extraction with normal ammonium acetate. In the absence of a flame photometer, a turbidity method has been standardized. The soil is extracted with Morgan's reagent (10% sodium acetate in 3% acetic acid solution). The turbidity is developed by sodium cobaltinitrite. The turbidity is measured by a photoelectric colorimeter.

Available phosphorus is estimated after extraction by 0.5 M $NaHCO_3$ with pH 8.5, after Olsen's procedure. The colour is developed by the use of ammonium molybdate and stannous chloride. The colour intensity is measured with the help of a photoelectric colorimeter.

The alkaline permanganate method is sometimes used for available nitrogen. This method has not always given satisfactory results. Organic carbon is used in most laboratories as a guide for nitrogen fertiliser recommendation. Organic carbon is determined by colorimetric procedure of Datta *et. al.*, (1962).

pH is measured by the pH meter on a 1:2 soil-water extract. Conductivity is estimated by the "solubridge", or on any standard conductivity meter, on the same soil-water suspension used for pH.

For detailed methods, the reader is referred to a bulletin on *Soil Testing in India* by G. Muhr, *et. al.* (1963) published by the U.S. Agency for International Development Mission to India, New Delhi.

Soil test interpretation : The soil testing laboratories classify the results of soil tests as *low*, *medium* or *high*. The standards followed at IARI, New Delhi, and the state soil testing laboratories in India are given in Table 17.2.

TABLE 17.2

RATING CHART FOR SOIL TEST DATA IN INDIA

	Low	*Medium*	*High*
		(Pounds per acre)	
Available Nitrogen	below 250	250-500	above 500
Available P_2O_5	below 20	20-50	above 50
Available K_2O	below 125	125-300	above 300
Organic carbon (used as a measure of available nitrogen)	below 0.5%	0.5-0.75%	above 0.75%
	Acidity (pH)		
Acidic	pH below 6.0	Tending to become alkali soil	pH 8.5-9.0
Normal for most of common crops	pH 6.0-8.5	Alkali soil, harmful for most crops.	pH above 9.0
	Conductivity (total soluble salts) (millimhos)		
Below 1	Normal		
1 — 2	Soluble salt content critical for germination		
2 — 3	Salt content critical for the growth of salt-sensitive crops.		
above 3	Severe injury to most crops.		

Source Muhr, G., et. al. *Soil Testing in India*, U. S. Agency for International Development Mission to India, New Delhi, 1963.

There is a greater probability of obtaining a profitable response from the use of fertilisers on soils testing "*low*" in an element than on soils testing "***high***" in that element. The extent of response with different soil test ratings is illustrated in Figures 17.11 and 17.12.

Calibration of soil tests and fertiliser recommendation : Soil tests by themselves would be of no value unless they have been calibrated with crop responses. If the results obtained from the laboratory tests correlate well with the results from fertiliser experiments in the field, it is a good test. The Indian Agricultural Research Institute, New Delhi, has done such correlation studies with a number of soils from various parts of India. As a result of these studies, suitable analytical methods have been recommended and fertiliser recommendation prescribed.

In order that the fertiliser recommendations become more useful, more calibration studies of soil tests with response of different crops should be undertaken under all agro-climatic conditions in each country. This information should be obtained from field and greenhouse fertility experiments conducted on a wide range of soils. Yield responses from applied nutrients can then be more closely related to the quantity of available nutrients in the soil as found by soil analysis. Accurate fertiliser

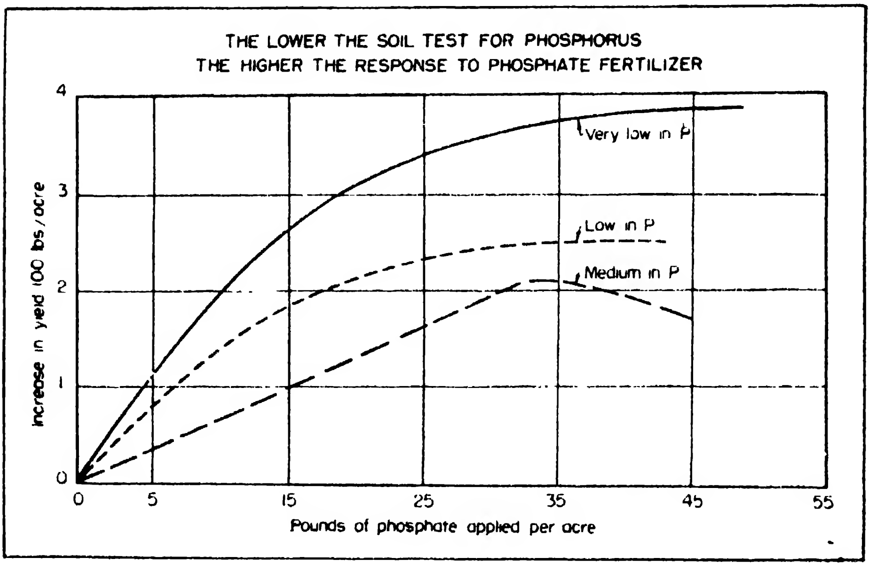

Fig. 17.11 There is a greater probability of obtaining an increase in yield of wheat from the application of phosophorus fertiliser when the soil tests "very low" or "low" in phosphorus than when it tests "medium" *(Courtesy American Potash Institute)*

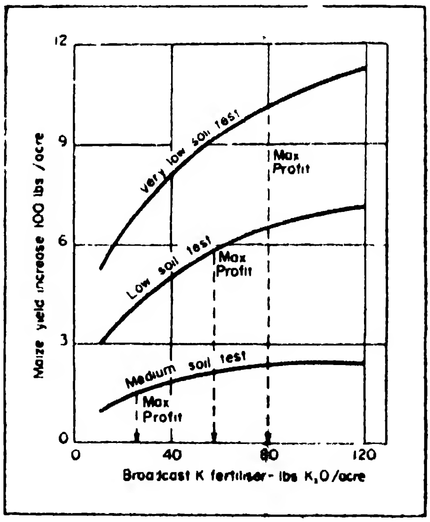

Fig. 17.12 The lower the soil test for potassium the higher the response of maize (corn) to potassium fertiliser. *(Courtesy American Potash Institute)*

recommendations based on soil-test-crop-response correlation studies in every country will make the soil testing service more useful and popular and will result in the more efficient use of fertilisers to obtain maximum crop yields.

4. PLANT ANALYSIS

The analysis of the plant to evaluate soil fertility may consist of total analysis, plant tissue tests and biochemical methods.

Total analysis : Plant analysis is based on the fact that an element deficient in the soil would be present in the plant in small amounts. In view of the shortage of one nutrient, the other nutrients would tend to accumulate because of poor utilization. Further, a nutrient such as potassium may be present in adequate amounts in the soil yet its availability to plants may be limited due to an excessive amount of lime. Despite some short-comings, the method of plant analysis has proved useful in preliminary diagnosis of deficiency diseases, particularly in fruit trees. Leaves of the same age from healthy and diseased plants, or high-and-low-yielding plants can reveal the presence of a deficient element.

The plant material to be analysed is ignited and the hydrochloric acid extract of the ash is prepared. The acid extract is then analysed for several nutrients. The critical levels have been suggested for nutrient elements in a number of plants. The critical level is the per cent composition below which the growth of a plant is limited and response from fertilisers can be expected. For example, Takahashi of Japan has reported that rice plant which contains less than 1.0 per cent K_2O in the straw is deficient in potassium. At times the range of a critical limit varies with the level of other nutrients. For example, in the case of boron, the critical limit is higher when the calcium level in the plant is high than when the calcium level is low. The effect of average annual rainfall on the chemical composition of soils and grasses is shown in Table 17.3.

TABLE 17.3

THE INFLUENCE OF ANNUAL RAINFALL ON THE COMPOSITION OF SOILS AND GRASSES

Nutrient	Hissar* (Rainfall 28 cm.)		Kangra (Rainfall 320 cm.)	
	Soil %	Grasses %	Soil %	Grasses %
Nitrogen	0.053	0.34	0.161	0.56
Phosphorus	0.155	0.40	0.077	0.13
Potassium	1.680	1.22	0.544	0.38
Calcium	0.825	0.77	0.431	0.66
Magnesium	1.048	0.22	0.704	0.18

* Hissar and Kangra are Districts in Punjab, India.

Source : Nijhawan, S.D. *Healthy Soils make Healthy Men.* Indian Farming Vol. VI, No. 3, June 1960.

In acid soils, available manganese is high and may become toxic to plants. Apple leaves with more than 300 p.p.m. of manganese indicate toxicity. Liming of soil to raise the pH to 6.0 or above reduces manganese toxicity.

Plant tissue tests : These tests are rapid and are essentially qualitative. The nutrients are absorbed by roots and transported to those parts of plants where they are needed. The concentration of cell sap is usually a good indication of how well the plant is supplied at the time of testing.

The plant parts, usually leaves, are removed and plant sap is extracted. The plant sap is usually tested for nitrate, phosphorus, and potassium. The use of a specific reagent for each nutrient to be tested develops the colour. The intensity of colour is a qualitative measure of the content of the particular nutrient.

For details of the method for preparing reagents used in making the chemical tests on plant tissue for nitrate, phosphate, and potassium the reader is referred, to "Diagnostic Techniques for Soils and Plants" edited by Kitchen, H.B. (See References).

Biochemical methods : Mineral nutrients are known to serve as activators for enzyme systems. Certain mineral nutrients such as phosphorus and magnesium activate a large number of enzymes, whereas others mediate in a limited number of specific enzyme reactions. For example, molybdenum is required for nitrate reductase enzyme essential for the reduction and utilization of nitrates in plants. Thus enzyme activity may be correlated with the presence of specific mineral nutrients in plants. The first such attempt was probably made by Doby and Hibbard (1927). These workers found higher activity of amylase and invertase in potassium-deficient sugar beets. Since the work of Doby and Hibbard, several workers have attempted to correlate enzyme activity with nutrient supply. A few examples of such work will be mentioned here.

Pattanaik (1950) found an increase in catalase activity as a result of adding boron in concentration of 1 p.p.m. to the culture medium of rice. The same worker found that the leaves of rice plant had a maximum activity of catalase when the manganese content of the medium was 5 p.p.m.

Anderson and Evans (1956) reported that the activities of isocitric dehydrogenase and malic enzyme in extracts from plants of dwarf bean (*Phaseolus vulgaris*) depended on the manganese supply.

Kessler (1961) from Israel has reported interesting results on the relationship of ribonuclease activity and zinc deficiency in orchard trees. It would be seen that low ribonuclease activity promotes net synthesis of ribonucleic acid while high ribonuclease activity shifts the reaction to

hydrolysis. Optimal zinc concentrations keep the ribonuclease activity at the lower range, thus promoting synthesis of ribonucleic acid and protein. At deficient zinc concentrations, ribonuclease activity was high, resulting in destruction of ribonucleic acid. High zinc concentration suppressed the ribonuclease activity to a very low rate, resulting in suboptimal synthesis of ribonucleic acid with a corresponding reduction in protein synthesis.

Other workers have shown a relationship between nutrient supply and auxin activity in plants. Skoog (1940) in his experiments on tomatoes and sunflowers grown in zinc-deficient culture solutions found little or no auxin activity in zinc-deficient plants.

Biochemical studies such as the relationship of soil fertility to enzyme activity offer challenging opportunities. The only difficulty is that such methods require costly equipment and can therefore be done only in a few laboratories.

5. SIMPLE FIELD EXPERIMENTS ON FARMERS' FIELDS

The crop yields in most of the farmers' fields are very low as compared to those observed on well-managed government farms. This is primarily due to the use of manures and fertilisers, good seed and adequate plant protection on government farms. The soil fertility level of an average farm in Tropical Asia is very low. Thus the results of experiments on government farms will usually not represent the fertiliser requirement of most farmers' fields. Mukerjee's and Sinha's simple experiments on cultivators' fields in Bihar state (India) helped to discover the deficiency of potassium in Bihar soils. Before such experiments, potassium was not considered necessary for most crops. These experiments have therefore proved useful in detecting hidden hunger in plants and served as good demonstrations on the value of fertilisers. Besides, as the response of crops to fertilisers vary depending upon the soil, climate, and other factors, more experiments can be done economically on a large number of farmers' fields. Thus the experiments are done in places where the results are to be applied.

The popular types of simple fertiliser trials in India are as follows : (1) Eight-plot trials ; with O,N,P,K, NP. NK, PK, and NPK. Responses to the three major nutrients in all combinations are thus found. (2) Seven-plot trials, with no fertiliser, ammonium sulphate at 20 lbs. N per acre ; ammonium sulphate at 40 lbs. N per acre ; urea at 20 lbs. N per acre ; urea at 40 lbs. N per acre ; calcium ammonium nitrate at 20 lbs. N per acre and calcium ammonium nitrate at 40 lbs. N per acre.

The results showed that there is a general deficiency of nitrogen in the soils of India. Phosphorus was found to give increased yields on nearly all crops, especially when used with nitrogen. Potassium gave an increase in yield of more crops on more soils than was previously known. In the source-of-nitrogen trials, all forms of nitrogen gave approximately equal crop response per pound of nitrogen. The only exception was that calcium ammonium nitrate should not be used as a basal application for rice because most of the nitrate nitrogen was lost by denitrification as gaseous nitrogen.

Similar trials with suitable modifications are being conducted in Pakistan, Burma, Thailand, Taiwan, and Philippines.

6. COMPLEX FIELD EXPERIMENTS

Simplex fertiliser experiments on farmers' fields have provided a powerful tool in the hands of agricultural scientist in advising the correct type and amount of fertiliser for various places. These experiments, however, suffer from certain defects. The large number of factors cannot be tried in one experiment in which the interaction of one factor with another can be assessed. For example, in one experiment on the Bagwai Experimental Farm (M.P., India) nitrogen and phosphate singly gave a small response in paddy yield. The combination of nitrogen and phosphate gave an increased yields which was higher than the sum of increased yields due to nitrogen and phosphate when used singly. This kind of interaction may be observed only when a number of factors are being tried, including the amount of fertiliser, the method of application, and the number of irrigations. This is possible only on well-managed experimental farms.

Complex fertiliser experiments attempt to determine the correct kind of fertiliser, amount, and method of application for each soil-climatic zone. Agronomic trials on an extensive scale in India were first initiated with the help of U.S.A.I.D. and are now being undertaken by Indian Council of Agricultural Research. They have proved extremely useful in providing correct information about fertiliser use and determining nutrient deficiencies. Recently trials with micronutrients have also been initated in experiments.

Field experiments conducted in certain places in India have shown the beneficial effects of micronutrients (besides the major nutrients) on several crops. This kind of "hidden hunger" may not be detected by visual symptoms. The soil deficiency may either decrease the content of the particular nutrient or decrease the yield, or both. Field experiments provide the means for finding the nutrients necessary to increase crop yields.

7. MITSCHERLICH TECHNIQUE

This method was developed by the German scientist, Mitscherlich. He developed his "Law of Physiological Relationships", which stated that, "plant yield could be increased by each single growth factor even when it was not present in minimum as long as it was not present in optimum. Mathematically his concept is expressed as $dy/dx = C_1(A-Y)$, where dy/dx is the rate of increase in yield produced by the factor x ; A=the maximum yield obtainable by increasing x under given conditions ; C_1=proportionality constant which may be called efficiency factor ; and Y=actual yield. In the original Mitscherlich technique, oat plants served as test plants and were grown to maturity. The soil is mixed with two parts of pure quartz sand and 18 pounds of soil-quartz sand mixture (6 lbs. soil+12 lbs quartz sand) which is put in glazed pots 20 cm. in diameter and 20 cm. in depth, with a drainage hole. The treatments are—one pot no nitrogen, ; three pots no potassium (NP) ; three pots no phosphate (NK) ; and three pots complete fertiliser (NPK). A total of 10 pots is used for a single test. The following plant nutrients are supplied per pot for the fertiliser treatment.

1.0 gm. N as ammonium nitrate in 20 ml.

1.5 gm. K_2O as potassium sulphate in 50 ml.

1.1 gm. P_2O_5 as superphosphate in 50 ml.

TABLE 17.4

MITSCHERLICH YIELD TABLE FOR POTASSIUM AND PHOSPHORUS

Soil Content		Yield as Percentage of Highest Yield	
Doppel-Zenters per hectare	Pounds per acre	Potassium	Phosphorus
0.1	8.93	19.3	12.9
0.2	17.86	34.8	24.1
0.3	26.78	47.4	33.9
0.4	35.72	57.5	42.4
0.5	44.65	65.7	49.9
0.65	58.05	75.1	59.3
0.85	79.05	83.8	69.1
1.0	89.3	88.2	74.9
1.2	107.16	93.3	80.9
1.5	133.95	96.0	87.4
2.0	178.60	98.6	93.7
3.0	267.90	99.8	98.4
4.0	357.20	100.0	99.6
5.0	446.50	100.0	99.9
Efficiency factor:		0.93	0.60

Source : Mitscherlich, E.A. *Die Bestimmung des Dunger bedur Frisses des Bodens* 3rd ed. 1930. Verlag Paul Parey Hedemannstrass 29-28, Berlin S.W. 11.

Twenty-five plants are grown to maturity in the field or in a greenhouse. The yield of complete fertiliser treatment is regarded as the maximum possible and is considered as 100 percent. Yields of NP and NK treatments are then calculated as per cent of the maximum. This percentage figure is then used to find the available soil phosphorus (P_2O_5) and potassium (K_2O) in pounds per acre by reference to a table constructed by Mitscherlich (Table 17.4). From the same table, predictions as to the percentage increase in yield expected from the addition of given amounts of nutrients can be obtained.

8. NEUBAUER SEEDLING METHOD

This technique is based on the uptake of nutrients by a large number of plants grown on a small amount of soil, so that the available nutrients are assumed to be completely exhausted from the soil. The nutrients so removed are determined by chemical analysis of the entire plant.

The soil samples are air dried and passed through a 1 mm. sieve. One hundred gm. of soil are mixed with 50 gm. of coarse sand (particle size 0.5-0.9 mm.) and placed in a dish 11 cm. in diameter and 7 cm. deep. A piece of glass tubing 1 cm. in diameter is inserted in the centre to facilitate watering, and 250 gm. of fine sand moistened with water are placed on top of the soil-sand mixture. The total moisture is 80 gm. One hundred rye seeds are grown for 17 days in the dish. The seedlings. are then harvested and analyzed for phosphorus and potassium.

Blank experiments are also done, using 100 gm. fine sand in place of soil. Rye seedlings (100) are sown, harvested and analysed. The blank values should correspond to 96% of total K_2O and 89% of total P_2O_5 of the seed.

Blank values are deducted from values determined with soil. The net values obtained are designated as "root soluble" quantities of the soil. These values are compared with similar values from soils giving high yields of crops. On the basis of the difference in the two values, fertiliser applications are recommended.

Neubauer calculated the fertiliser requirements for particular crops on two main assumptions :

(1) That under the conditions of the test the seedlings absorb the total quantity of available potassium and phosphorus in the soil, and

(2) Crops under field conditions can only utilize a certain fraction of the total amounts due to the different conditions of growth. He has given the percentage utilization coefficients as follows :

For K_2O -- Barley 12%, wheat 15%, potatoes 25%.
For P_2O_5 — Barley 20%, all other common plants 33%

Neubauer's seedling method has also been used for determining the availbility of calcium and micronutrients.

9. USE OF INDICATOR PLANTS

Certain plants are suited as indicators for specific nutrient deficiencies. The indicator plants are susceptible to such deficiencies and develop clear symptoms which are not shown by other deficiencies. Some of the common crops suitable as indicator plants are given as follows :

Deficient element		*Indicator plants*
Nitrogen	—	Cauliflower, cabbage
Phosphorus	—	Rape
Potassium	—	Potato
Calcium	--	Cauliflower, cabbage
Magnesium	—	Potato
Iron	--	Cauliflower, cabbage, potato, oat.
Sodium	---	Sugar beet
Manganese	—	Sugar beet, oat
Boron	—	Sunflower.

Wallace has suggested the design of field experiment combining the different indicator plants in a manner that in a single experiment, the possibility of a number of nutrient deficiencies can be tested.

Sunflower has been used for detecting boron deficiency. A small quantity of soil (about one pound) is placed in a tall fruit can. The soil is given a complete nutrient solution minus boron. Five sunflower seedlings are planted. The boron deficiency is judged by the number of days in which the deficiency symptoms first appear. If deficiency appears in 28 days, the soil has marked boron deficiency. If the symptoms appear in 28-36 days, mild deficiency is prevalent, while if the symptoms appear after 36 days, little or no deficiency is considered.

Sand cultures with increasing amounts of boron are also used to determine the absolute amounts of boron by correlating the appearance of deficiency symptoms with the amount of boron added.

10. VISUAL DIAGNOSIS

Plants show hunger signs which can be detected by careful observation and study. These signs are specific when deficiency is acute and caused by a single nutrient. In most cases considerable experience is necessary for their recognition.

The typical deficiency symptoms developed by nutrient deficiencies are described :

A. Deficiency symptoms on older or lower leaves.

(i) *Nitrogen deficiency* : A sickly yellowish green colour. A distinctly slow and dwarfed growth. Drying up or 'firing' of leaves which starts at the bottom of the plant, proceeding upwards. In plants such as maize, grains, and grasses, the firing starts at the tip of the bottom leaves and proceeds down the centre or along the mid-rib.

(ii) *Phosphorus deficiency* : Purplish leaves, stem, and branches. Slow growth and late maturity. Small slender stalk and low yields of grain, fruit, and seed.

(iii) *Potassium deficiency* : Lower leaves scorched or burnt on margins and tips. The dead areas may fall out, leaving ragged edges. In cereals and grasses, firing starts at the tip of the leaf and proceeds down from the edge usually leaving the mid-rib.

(iv) *Magnesium deficiency* : A general loss of green colour between the veins which starts in the bottom leaves and later moves up the stalk. The veins of the leaf remain green. Cotton leaves often turn purple-red between the green veins. Dead areas develop between the veins very suddenly.

(v) *Zinc deficiency* : Yellow striping of the leaves between the veins. The plants are severely dwarfed and older leaves die.

B. Effects localized on new leaves :

I. Growing tips usually dead.

(vi) *Calcium deficiency* : Young leaves in terminal bud become "hooked" or wrinkled in appearance. Dead spots at tip and margin of young leaves. Death of roots actually preceding all the symptoms. Roots are short and much branched. Light green band along margin of leaves.

(vii) *Boron deficiency :* Young leaves from the terminal bud becoming light green at the base, with final breakdown. Stems and leaf stems brittle. Death of roots, particularly growing tips. Definite rosette appearance of plants due to failure of internodes to elongate.

Fig. 17.13 Iron deficiency on lemon leaves. **Left:** Normal **Right:** Severe iron deficiency. Leaves in the middle are intermediate in iron deficiency (*Courtesy : California Agricultural Experiment Station*)

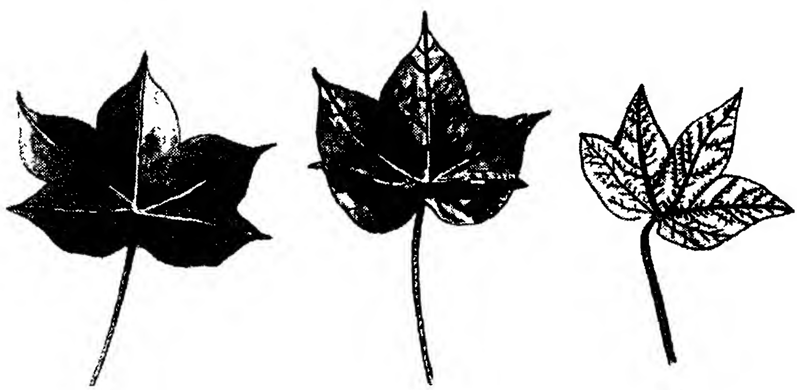

Fig. 17.14 Manganese deficiency on cotton leaves. **Left** : Normal leaf. **Middle : Initial** stage of manganese deficiency **Right** : Severe manganese deficiency. (*Courtesy : National Plant Food Institute, U.S.A.*)

II. Growing tips remaining alive.

(viii) *Iron deficiency :* Leaves yellowing between the veins, larger veins remaining green. Young leaves are chlorotic. In extreme cases death of margins and tip of leaves. (Figure 17.13).

(ix) *Manganese Deficiency* : A general paleness of the leaves, with dead spots usually present and scattered over the leaf surface. The veins remain green. (Figure 17.14).

(x) *Sulphur deficiency :* Leaves light green, veins lighter than adjoining interveinal areas. Some dead spots ; little or no drying of older leaves ; immature fruit, light green in colour.

(xi) *Copper deficiency* : Young leaves permanently wilted without spotting or marked chlorosis.

The deficiency symptoms may be complicated due to drought, sunburn, attack of plant pests or diseases, water-logging, alkaline soil conditions, chemical spray injury, or toxic effects of excessive mineral nutrients.

II. FOLIAR SPRAYS

The visual diagnosis based on hunger signs should be confirmed by foliar sprays, or chemical analysis of plant and soil. Often iron and manganese deficiency symptoms resemble each other. A spray with ferrous sulphate and manganese sulphate in different rows of crops would confirm the preliminary diagnosis whether the deficiency is due to iron or manganese.

Foliar sprays can also be used after preliminary diagnosis has been made on the basis of plant analysis. In Maharashtra State, India, the leaves of citrus plants affected by dieback disease were analyzed for micronutrients. The healthy plants were also analyzed for comparison. The results are given in Table 17.5. These results showed that dieback disease was found

TABLE 17.5

IRON, MANGANESE, COPPER, AND ZINC CONTENT OF LEAVES OF SANTRA ORANGE *(CITRUS AURANTIUM* VARIETY *CINTRA)*

Condition of leaves	Iron	Manganese (Parts per million)	Copper	Zinc
Diseased	57.50	33.11	5.53	11.79
Healthy	62.74	35.87	8.52	16.92

Source : F.R. Bharucha and S. David, *Proceedings of Symposium on Trace Elements in the Nutrition of Plants and Animals.* National Institute of Sciences of India, New Delhi, 1955, pp. 69-80.

to be associated with copper and zinc deficiency. Iron deficiency was not well established. These results were confirmed by foliar sprays. Bharucha and David (1955) reported that die-back disease was checked by spraying the affected trees with a combination of copper and zinc sulphates (0.2-0.4% of each in one half gallon of water per tree). Response to spraying was manifest in 3 to 4 days after treatment.

Micronutrients such as, iron, zinc, copper, and manganese are fixed in the upper layers of fine clay or calcareous soils and little if any may be available to the feeding roots, particularly of perennial plants. Thus it is difficult to correct deficiency by soil applications. The use of foliar sprays is the most effective and quickest method for correcting such deficiencies.

The important points to be considered in spraying are : (1) use of the correct strength of spray, as cencentrated solutions may damage the foliage, (2) The use of a wetting agent, as certain foliage is difficult to wet. Various wetting agents such as ester salts and blood albumin have been used.

A combination of methods is often used to diagnose a physiological disease in crop plants ; for example, chlorosis of citrus leaves (called "mottling" in Madras and "frenching" in Coorg) is a common disease. The symptoms are a yellow intervenal chlorosis with veins remaining green. An excellent positive correlation was obtained between the micronutrient content in the soil and in the leaves and the response to foliar sprays.

12. *AZOTOBACTER* PLAQUE TEST

The general requirements of mineral nutrients for certain types of microorganisms are similar to those of certain crop plants, although the absolute amounts differ. Organisms of the *Azotobacter* group are particularly sensitive to soil acidity and to a low level of phosphorus. Advantage of this fact is taken in determining the deficiencies of lime, phosphorus, and potassium.

With Winogradsky's work as the basis, Sacket and Stewart (1931) modified the method for finding out mineral deficiencies of Colorado soils in the U.S.A. Joshi and Ayyar (1934) have used Sacket's technique with slight modification for Indian and Pakistan soils. Joshi's and Ayyar's method is as follows :

One hundred gms. of air dry soil are mixed with 5 gm. of starch. The mixture is divided into four equal parts. The first part is treated as control and no addition of any nutrient is made. To the second part 2.5 ml. of 3 per cent K_2SO_4 solution is added to test for potassium deficiency. To the third part, 2.5 ml. of 6 per cent Na_2HPO_4 is added to

test for phosphorus deficiency. The fourth part receives 2.5 ml. of 3 per cent K_2HPO_4 to test for both potassium and phosphorus deficiencies. The control and all treatments are with *Azotobacter*. The soil is properly moistened and kneeded and incubated for 72 hours. The abundance of *Azotobacter* colonies is recorded as a qualitative measure of phosphorus, or potassium deficiency in the soil.

Eight Indian and Pakistan soils of varying pH and texture were tested by this technique. The results are given in Table 17.6. All the above soils

TABLE 17.6

RESULTS OF *AZOTOBACTER* PLAQUE TEST FOR POSSIBLE NUTRIENT DEFICIENCIES IN INDIAN AND PAKISTAN SOILS

Location of Soils Sample	pH	Control	K_2SO_4	Na_2HPO_4	K_2HPO_4
Pusa	7.9	0 *	0	+	+++P
Kalyanpur	7.3	0	0	++	++++P
Krishnanagar	7.3	+ F	0	++	++++P
Chinsurah	7.2	0 F	0	+++P	+++P
Ranchi	6.0	0	0	0	0
Sailkot	7.3	0 F	0 F	++++P	++++P
Gujranwala	8.1	0	0	+++P	+++
Dacca	5.9	0	0	0 A	0 A

Source . Joshi, N.V. and C.S. Ram Ayyar Indian Journ. Agri. Sci. Vol. IV, Part I Feb. 1934. pp.-166-176.

* *Legend*

0 -	No *Azotobacter*	P—Pigmented
+ —	Scanty growth of *Azotobacter*	A Actinomycetes
++	Average growth of „	F—Fungus
+++	Moderate growth of „	
++++	Luxuriant growth of „	

tested are deficient in phosphorus and would respond to phosphate fertilisation. The soils of Ranchi and Dacca being acidic, did not respond to phosphate. Lime deficiency is clearly manifested.

Azotobacter plaque method is of value in detecting deficiencies of lime, phosphorus and potassium. The method is not sensitive to distinguish between varying degrees of phosphorus requirements of soil. The method can also be used to test the effectiveness of various phosphatic fertilisers.

13. *ASPERGILLUS NIGER* TEST

The *Aspergillus niger* test uses a solution rather than a plaque technique. A small amount of soil is mixed with a nutrient solution inoculated with a suspension of *Aspergillus niger* and incubated at 35°C for 4 days. The

weight of the mycelial pad is used as a measure of nutrient deficiency. Mehlich *et. al.* (1933) modified the method by using the amount of potassium absorbed by mycelial pad as a measure of nutrient deficiency. An example of the criteria used is shown below :

Weight of 4 pads of *Aspergillus niger*	K_2O absorbed by *Aspergillus niger* per 100 gm. of soil	Degree of K deficiency
1.4 gm.	15 mg.	very deficient
1.4—2.0 gm.	15—20 mg.	moderate to slight deficiency
2.0 gm.	20 mg.	not deficient

This test has also been used to determine copper, magnesium, molybdenum, cobalt and manganese requirements. The colour of the mycelia and spores is used as a measure of the amounts of copper or manganese present

14. *CUNNINGHAMELLA* PLAQUE METHOD

Mehlich, Fred, and Truog have developed this method for determining phosphate requirement of soils. The soil is mixed with a nutrient solution, moistened to a paste and spread uniformly in the well of an especially constructed clay dish inoculated on the surface in the centre of the paste, and allowed to incubate for 4½ days. The diameter of the *Cunninghamella* mycelia is used as criteria for the amount of phosphorus present.

15. CARBONDIOXIDE EVOLUTION METHOD

Desai and Sundara Rao have used the CO_2 evolution method as a criterion for determining nutrient deficiency. A known quantity of soil is taken in each of 500 ml. conical flasks. The soil receives different treatments such as compost, ammonium sulphate, susperphosphate, and potassium chloride. The flasks are sealed, and incubated for 10 days. At the end of this period the CO_2 produced is measured by absorption in standard $Ba(OH)_2$. The excess barium hydroxide is titrated with standard HCl. The principle of the method is that microorganisms require all of the major elements for their activity and a deficiency of any nutrient would depress the amount of CO_2 produced. The addition of the deficient nutrient would increase the carbondioxide produced.

Desai, Rao, and Tejwani (1945) have used this technique for determining nutrient deficiencies in Delhi soils. It was found that the Delhi soil was deficient in nitrogen and phosphate. Crops grown in lysimeters confirmed these findings.

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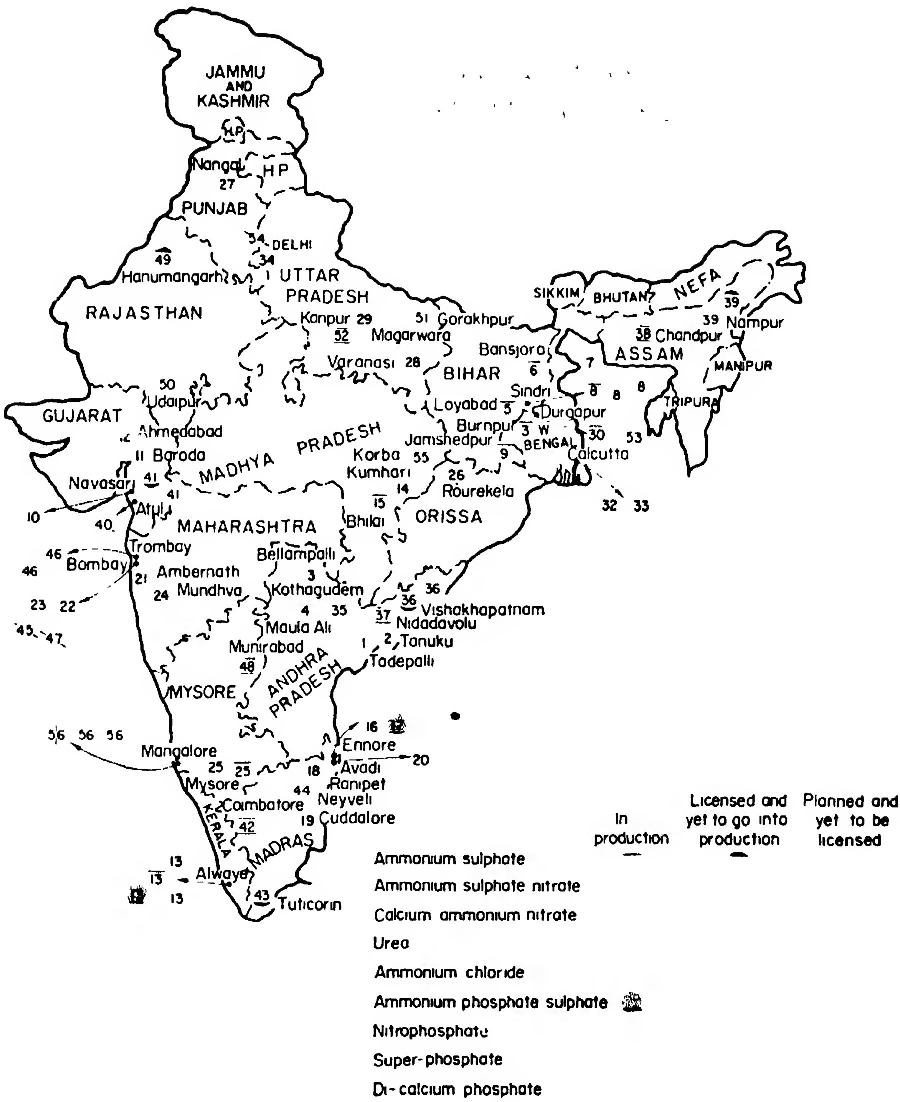

Courtesy The Fertiliser Association of India, New Delhi.

CHAPTER EIGHTEEN

SOIL-FERTILISER PROBLEMS OF DEVELOPING COUNTRIES

" *We can delay the evil day when population will greatly exceed the food supply for some time by improving agriculture ; but unless something is done to slow down the rate of population growth, eventually Malhus will win.*"

RICHARD BRADFIELD, 1960.

The population in many developing countries is growing rapidly and would exceed food production unless energetic and urgent steps are taken to maximise production. In fact the growth of population is neutralizing much of the net economic development taking place. There is a great "nutritional gap" for the present populations of different regions in the world. There is another "nutritional gap" between the food available now and the food needed to provide reasonable nutritional standards for the world's future population. World population is estimated to increase by 22 per cent in 1970 as compared to 1958. The problem of feeding the growing population is appreciated by most people but the solution to the problem is not always available.

I. PRESENT FOOD SUPPLIES AND NEEDS FOR FUTURE

It has been estimated that the average per capita requirement is 3,000 calories per day, with about 80 grams of animal protein (or high biological value protein). Even allowing that the people in the tropics may require

less calories than those in cold countries, the data provide evidence that 52 per cent of world population have poor nutritional standards and 19 per cent have medium standards. A recent survey by FAO of the United Nations reports that 10-15 per cent of the world's population is under-nourished and that up to 50 per cent of the world's population suffer from malnutrition. The alarming fact is that the rate of increase in population is greatest in those areas where hunger and malnutrition are most prevalent. Parker has recently estimated food supplies available by regions of the world and the data are shown in Table 18.1.

TABLE 18.1

RECENT FOOD SUPPLIES AVAILABLE (PER CAPITA PER DAY)

Region	Calories	Total protein (grams)	Animal protein (grams)	World population (per cent)
Far East	2070	56	8	52
Near East	2470	76	14	
Africa	2360	61	11	19
Latin America	2470	67	25	
Europe	3040	88	36	
North America	3120	93	66	29
Oceania	3250	94	62	

Source. Parker F.W., *Fertilisers and Economic Development*. F.A.O., Rome.

Sukhatme of FAO has estimated world food needs for 1970, 1980, and for the year 2000. These estimates are based on estimates of increase in population with a reasonable increase in nutritional standards. It would be seen that total food needs would be greatest in those countries which have insufficient food requirements. This actually means that agricultural production must be increased at the rate of 5 per cent per year for the next 40 years. This is by no means an easy task. In India, the average annual increase in production for the period 1949—61 has been estimated at 4.3 per cent.

2. ROLE OF FERTILISERS IN AGRICULTURAL PRODUCTION

The increased food supplies needed now and in the future for developing countries can be achieved by increasing land under cultivation and by increasing production per acre, including the greater use of fertilisers. (Figures 18.1 and 18.2) Parker has estimated that as much as 25 per cent of the food required by the lesser developed countries could be obtained from the cultivation of *new* land. It should, however, be known that new land has special problems such as control of erosion, reclamation of saline or alkaline areas, and an insufficient supply of water. The nutritional gap can

Fig. 18.1 Rice is the principal food grain for human consumption in Tropical Asia. The problem of feeding a rapidly increasing population therefore lies mostly in increasing the yields of rice per acre. This demonstration in Central India resulted in a 91% increase in paddy (rough rice) per acre over the control when 30 pounds each of N, P_2O_5, and K_2O was applied O No fertiliser, Yield : 800 pounds of paddy N 30 pounds of N per acre, Yield : 880 pounds of paddy per acre. NP 30 pounds of N plus 30 pounds of P_2O_5 per acre. (The generalized State recommendation). Yield : 1,360 pounds of paddy per acre. NPK 30 pounds of N plus 30 pounds of P_2O_5 plus 30 pounds of K_2O per acre. Yield: 1,680 pounds of paddy per acre

Note : (1) Where N was applied, ½ of the N was applied at the time of puddling and the other ½ broadcast four weeks after transplanting (2) Where P and K were applied, they were all applied at the time of puddling. (*Near Jabalpur, Madhya Pradesh, India, 1963) (Courtesy Frank Shuman*)

best be met by proper use of fertilisers in combination with other improved agricultural practices such as an increase in the supply of water for irrigation, good seed, and adequate plant protection measures. The relationship of fertiliser use, crop yields, and density of population for selected countries is shown in Table 18.2. Even though the inherent soil productivity would show variation from country to country, the data in Table 18.2 shows the direct relationship of fertiliser use with crop yields.

TABLE 18.2

FERTILISER USE, YIELD, AND DENSITY OF POPULATION. (1961-62)

Country	Fertiliser Consumption (N+P_2O_5+K_2O) per hectare of arable land (kg.)	Density of population per hectare of arable land.	Yield per hectare (in 100 Kg)			
			Paddy	Wheat	Maize	Potato
Netherlands	457.74	11.33	—	39.3	39.0	281.0
Japan	270.17	15.49	47.0	27.4	27.0	177.0
Germany (West)	268.42	6.61	—	28.9	30.7	220.0
United Kingdom	190.71	7.28	—	35.4	—	224.0
U.A.R.	91.15	10.72	50.5	24.6	24.0	170.0
Italy	55.51	3.17	54.6	19.1	32.9	104 0
U.S A.	39.59	0.99	38 2	16.1	38.9	220 0
U.S.S.R.	10.53	0 95	24.0	10.6	18.5	95 0
India	2.35*	2.74	15.1	8.5	9.1	75.0

* Refers to 1960-61.

Source : *Fertiliser Statistics 1962-63*, Fertiliser Association of India, New Delhi.

Fig. 18.2 In Tropical Asia many local varieties of maize (corn) are grown but their yields per acre are very low. In several countries an adapted hybrid maize is being developed that responds to high levels of fertilisation. In Central India, this hybrid maize (Ganga 101) produced 7,946 pounds of maize (grain + cob) per acre when fertilised with 100 pounds of N, 60 pounds of P_2O_5, and 30 pounds K_2O per acre. The check plot not shown consisted of a local variety of maize with local cultural practices and yielded only 350 pounds of grain plus cob per acre. Maize is good for human food in Tropical Asia and in India is often eaten after it is roasted on the cob or the grain is ground and made in *chapatis*. (Near Jabalpur, Madhya Pradesh, India) (*Courtesy : Frank Shuman*).

The relationship between yield of paddy and fertiliser use in Taiwan for the period 1930-59 is illustrative of the role of fertilisers in increasing production (Figure 18.3). Figure 18.4 show the relationship of coffee yield and fertiliser use in Columbia, South America. Numerous such examples can be given. The enormous yields obtained in crop competitions show the great potentiality of increased production. Bradfield (1960) has given examples of the highest yields of important cereals. (Table. 18.3).

TABLE 18.3

WORLD RECORD YIELDS REPORTED IN LITERATURE

Crop	Yield Kg./Ha.	Grower	Location	Year	References
Maize (Corn) (Field)	19,100	Lamar Katliff	Baldwin, Prentise Co. Miss. U.S.A.	1955	Farm Journal Nov. p. 16
Maize (Corn) (Greenhouse gravel culture)	24,400	H.G.M. Jacobson	Conn. Agr. Exp. Sta. New Haven, Conn. U.S.A.	1948	Plant Physiol.23 : 636-37
Rice	13,400	Velliah Gounder	Thattampatti Village, Madras, India.	1950-51	The Record, U.S. Dept. of State Mar-Apr. 1952 : 26
Wheat	8,800	Turrel Bros.	Norfolk, England	1952	N. Y. TimesDec. 8, 1952.
	9,600	...	Soviet Union	1944	N.Y. Times, Dec. 8, 1952.

Source Bradfield, R. *Opportunities of Soil Scientists in Freeing the World From Hunger*. Presidential Address at the 7th International Congress of Soil Science, Madison, Wisconsin, U.S.A. 1960.

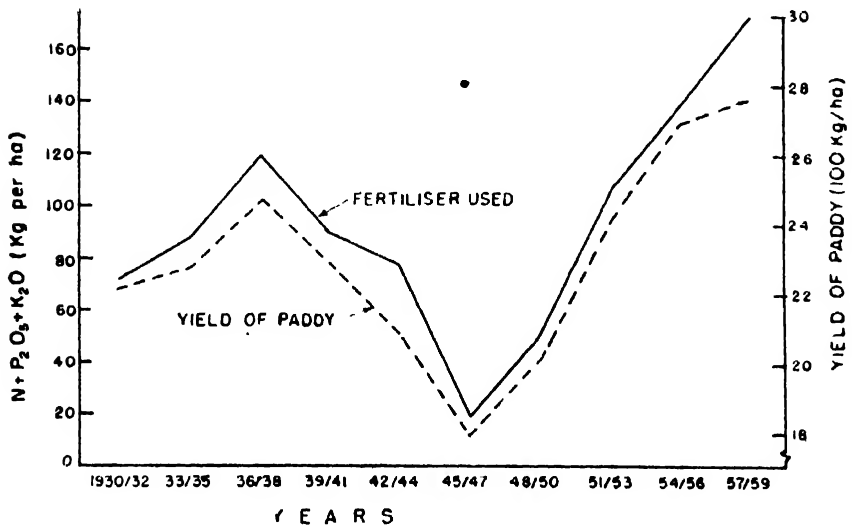

Fig. 18.3 Relationship between yield of paddy and fertiliser used (in terms of the nutrient). Taiwan, 1930-59 (by 3-Year averages) [*Source* : Williams, M.S. and J.W. Custon 1962. *Crop Production Levels and Fertilizer Use*, FAO, Rome]

The present day conditions in most developing countries are such that there is an awareness for increasing crop production ; and although the fertiliser use is intensified year after year, the efforts must be increased to offset the effect of growing populations and to improve nutritional standards.

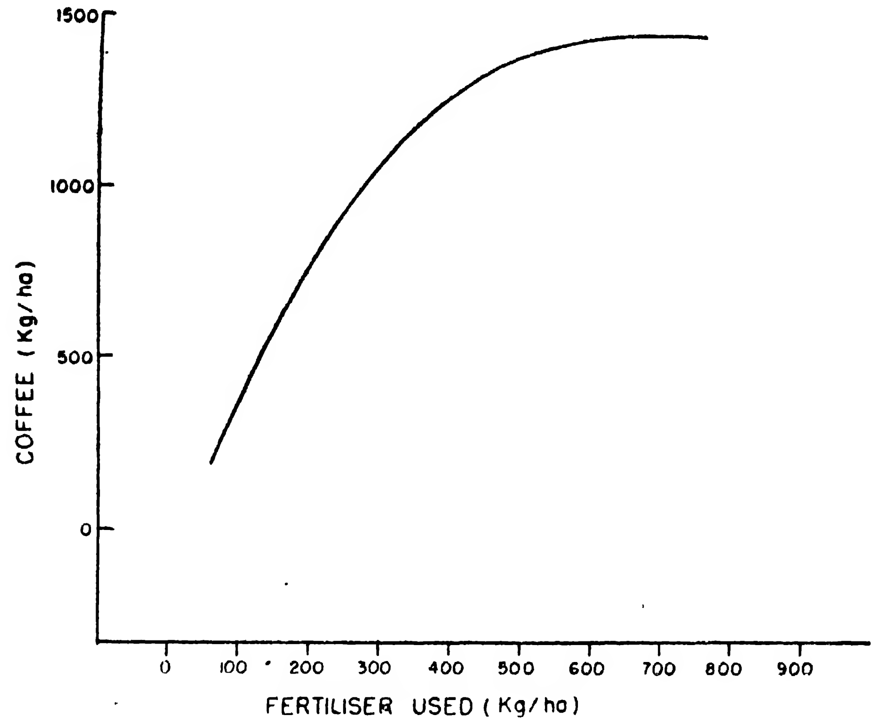

Fig. 18.4 Correlation between use of Fertilisers organic and mineral and yield of coffee on 27 farms in the Department of Caldas, Colombia, South America. *Source : ECLA/FAO, Rome, Coffee in Latin America Vol. I, 1958*

3. FERTILISER REQUIREMENTS

It has been mentioned that increased fertiliser use coupled with other improved practices offers the greatest scope for meeting the nutritional gap. Coleman (1963) has estimated the fertiliser requirement of nutritionally deficient regions of the world. Within 10 years, the fertiliser consumption should increase 5 times that of 1959-60 to meet the goal of providing adequate nutritional standards. The question is, can we achieve ths goal ? Coleman of the Sulphur Institute, Washington, D.C., has estimated that by 1970 the fertiliser nutrients consumption is likely to increase from 4.0 to 9.55 million metric tons, i.e., it would fall short of requirements by more than 10 million tons. This is a great challenge to be met by developing countries. (Table 18.4).

TABLE 18.4
FERTILISER REQUIREMENTS TO MEET 1970 NUTRITIONAL GOALS
[IN MILLIONS OF METRIC TONS OF PLANT NUTRIENTS ($N+P_2O_5+K_2O$)]

Region	*Used*	*Required*
	1959-60	1970
Far East	2.53	8.77
Near East	0.25	1.93
Africa	0.40	4.50
Latin America	0.82	4.06
Total	4.00	19.25

Source. Coleman, R. *World Fertiliser Requirements*. Fertiliser News 9(4) 7-14, 1964.

4. PLANT NUTRIENT RATIOS

The ratio of N : P_2O_5 : K_2O consumption in some of the countries of the world for 1961-62 is illustrated in Figure 18.5. India, Pakistan and many

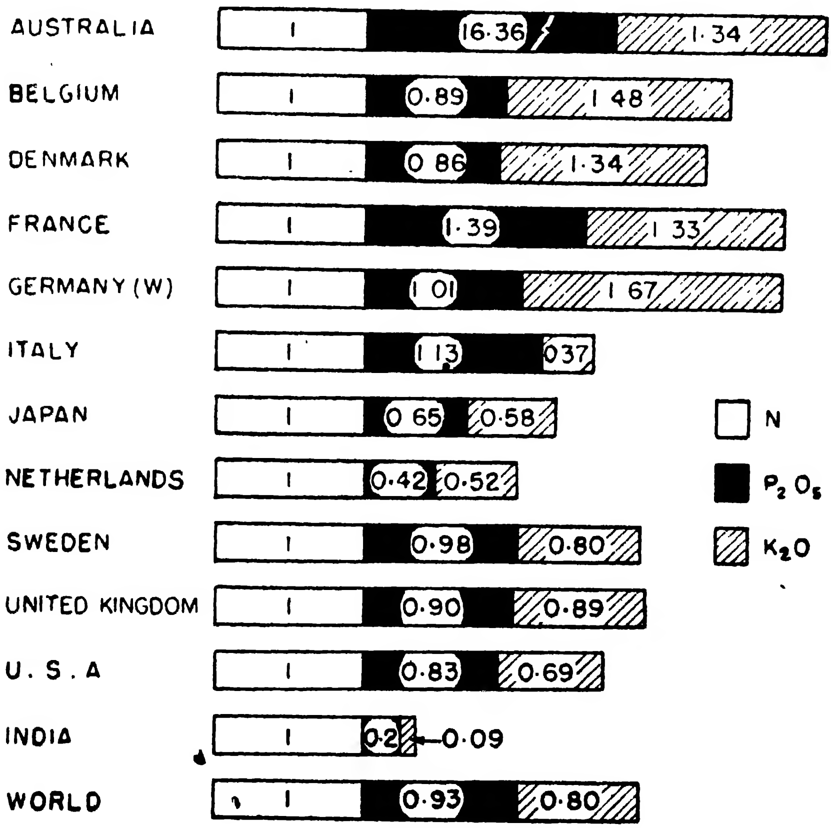

Fig. 18.5 A comparison of the ratio of N, P_2O_5: K_2O consumption in selection countries 1961-62 *Source : Fertiliser Statistics, 1962-63, Fertiliser Association of India, New Delhi*

other countries of Asia are using much more nitrogen as compared to phosphate and potassium. Many farmers are not using phosphate at all. While the use of nitrogen fertilisers has increased, the consumption of phosphatic fertilisers in particular is lagging behind the actual needs. There is a fundamental difference in the nitrogen and phosphate fertilisers. While the former is mobile or potentially mobile, the water-soluble and citrate-soluble phosphate fertilisers (superphosphate) react with the soil, become partially fixed, and are slowly released to plants. Due to this reaction of phosphate with soil, the crop responses have been lower than those with nitrogen and the farmers have not adopted the phosphate fertilisers so willingly as nitrogen fertilisers. Phosphate continues to give a residual effect for a number of years and helps to raise the soil fertility to a high level by improving soil properties for microbial and plant activity.

For the proper maintenance of soil fertility and keeping the soil in good health, it is imperative that phosphate is supplied in adequate amounts and placed in moist soil near roots where plants could make efficient use of it. Research is needed to improve placement implements to increase phosphate response. Extension methods are also needed to convince the farmer that phosphate is as important as nitrogen. Without the use of phosphate fertilisers, the increase in yields cannot be maintained for more than a few years with nitrogen fertiliser alone.

As nitrogen and phosphate fertiliser use increase, the need for potassium would also be felt. Presently (except in humid areas) general potassium needs are not great. Potassium fertilisers are now required for many special crops like potato, tobacco, chillies, and sugarcane, and where soil tests indicate the need for potassium. Five to seven years hence, we may have to think of large scale use of potassium fertiliser as well.

5. FERTILISER-VARIETY INTERACTION

Examples of fertiliser-variety interaction have been given in Chapter 16. Many local varieties can do well on low fertility soils but would not stand high fertilisation. Improved varieties do well only when fertilised. The present improved varieties have been bred on experimental farms, the fertility of which is higher than that of cultivators' fields, but is not high enough. Thus such varieties have limited potentiality on cultivators' fields even after fertilisation. The great need is for varieties that have genetic potentiality to respond to high fertilisation, i.e., they should have been bred or selected on high fertility soils. Under present conditions in India and Pakistan, wheat or paddy seldom respond to

nitrogen levels beyond 60 lb. N per acre. How can wheat in American and paddy in Japan respond to high levels of nutrition ? The answer to this question is their genetic ability and their selection under a high level of soil fertility. Thus we need to breed varieties under high fertility conditions and such varieties could be used for enlightened farmers and with specific recommendation to use high level of fertilisers, since these varieties may fail under low nutrition.

How fundamental studies on nutrient uptake by plants could help in promoting proper fertiliser use is illustrated in Figure 18.6.

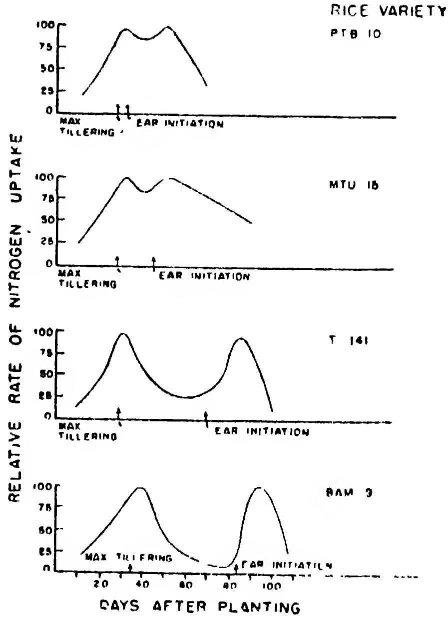

Fig. 18.6 Rate of nitrogen uptake of different rice varieties (*Source :* Tanaka, A., S. Patnaik and C.T Abichandani, *Studies on the Nutrition of Rice Plant (Oryza Sativa L.) Part IV Proc Ind. Acad Sciences, Vol XLIX. pp. 217-226) 1959.*

Rate of nitrogen uptake of different rice varieties show essentially two peak periods, at maximum tillering and after ear initiation. The number of days after planting when nitrogen requirement is maximum varies with the variety. We could make use of such fundamental information in giving nitrogen in split applications at the time when it is most needed. This would not only economise fertiliser use but would also bring higher returns per unit of plant nutrient. Similar kinds of information have been provided by Japanese workers on rice (Figure 16.4) and by American workers on maize (Figure 16.5). Since different crop varieties require nutrients at different times, such studies with different crop plants and varieties are necessary in promoting proper fertiliser use to achieve maximum economic crop yields.

6. SOIL TESTING

Soil testing service in India is relatively of recent origin. It is yet to be started in several Asian countries. The basic objectives of soil testing

service are to provide adequate service for testing the soils received from individual farmers and giving appropriate fertiliser recommendations. The basis for fertiliser recommendations in India is soil-test-crop-response correlation studies, made at IARI, New Delhi, in field and greenhouse conditions on different soil types. Examples of such correlations are given in Figures 18.7 and 18.8 and Table 18.5 and 18.6. Such studies have shown that Olsen's 0.5 M $NaHCO_3$ extraction procedure is a superior method for available phosphate estimation. Based on the frequency distribution of soil test values grouped according to per cent yield response the soils are classed as "low" (0-20 lbs. P_2O_5 per acre) "medium" (20-50 lbs. P_2O_5 per acre) and "high" (above 50 lbs. P_2O_5 per acre). This basis is used all over India in all states. Since such fundamental studies were made only at IARI, New Delhi, under particular climatic condition, the basic information cannot be complete unless such studies are made under different soil-climatic regions. There are indications that such grouping in "low", "medium", and "high" would vary in different states. Further the correlation of crop response with Olsen's method of available P_2O_5 may not be applicable for all soils. In acid soils, Bray's method is more applicable.

TABLE 18.5

CORRELATION COEFFICIENT OF SOIL-TEST VALUES FOR PHOSPHORUS BY VARIOUS METHODS IN GREENHOUSE EXPERIMENTS ON WHEAT AND RICE, AND 'A' VALUES

Method	Wheat			Rice		
	1955 n=6	1955-56 n = 11	Average	1955 n= 18	1955 n = 20	Average
0.5 M $NaHCO_3$, pH 8.5	+0.988†	+0.933†	+0.992†	+0.919†	+0.958	+0.943†
0.13 N HCl	+0.208	+0.186	+0.192	−0.03	+0.08	+0.029
0.1 N HCl + 0.3 N NH_4F	+0.562	+0.283	+0.367	−0.089	+0.045	−0.018
0.025 N HCl + 0.03 N NH_4F	+0.413	+0.381	+0.390	+0.140	+0.103	+0.120
0.002 N H_2SO_4, pH 3.0	+0.288	+0.359	+0.340	+0.286	+0.198	+0.239
1 per cent citric acid	+0.856*	+0.306	+0.522*	+0.207	+0.409	+0.318
CO_2	+0.027	+0.273	+0.208	+0.150	+0.093	+0.120
H_2O	+0.376	+0.412	+0.402	+0.132	+0.197	+0.167
Sodium acetate + acetic acid	−0.027	+0.273	+0.194	+0.155	+0.181	+0.169

*Significant at 5 per cent level † Significant at 1 per cent level

Source: Muhr, G.R. et. al, *Soil Testing in India*, U.S. Agency for International Development Mission to India, 1963.

TABLE 18.6

CORRELATION COEFFICIENT OF SOIL-TEST VALUES FOR PHOSPHORUS BY VARIOUS METHODS AND PER CENT YIELD RESPONSE IN FIELD EXPERIMENTS

Method	Wheat 1953—54 n = 27	Paddy, 1955 n = 17	Average for wheat and paddy
0.5 M $NaHCO_3$, pH 8.5	−0.413*	−0.515*	−0.452†
0.13 N HCl	−0.159	−0.147	−0.155
0.10 N HCl + 0.03 N NH_4F	−0.049	−0.114	−0.073
0.025 N HCl + 0.03 N NH_4F	−0.397*	−0.219	−0.334*
0.002 N H_2SO_4, pH 3.0 with $(NH_4)_2SO_4$	+0.057	−0.052	+0.017
1 per cent citric acid	−0.399*	...	...
CO_2	−0.239	...	...
H_2O	−0.154	−0.543*	−0.312
Sodium acetate + acetic acid, pH 4.8	−0.188	−0.186	−0.187

*Significant at 5 per cent level † Significant at 1 per cent level

Source: Muhr, G.R. et. al., *Soil Testing in India*, U.S. Agency for International Development Mission to India, 1963.

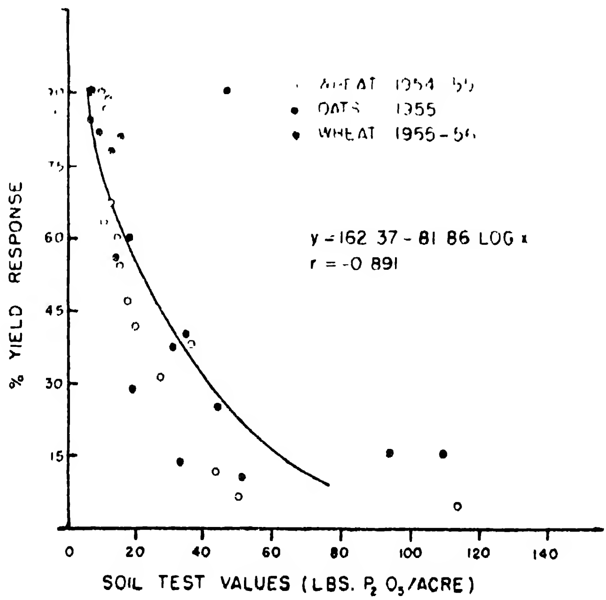

Fig. 18.7 Relationship between soil-test values for phosphorus by the Olsen's (0.5 M $NaHCO_3$) method and per cent dry matter yield response in greenhouse experiments on wheat and oats *Source* Muhr, G.R., et. al., (1963) *Soil Testing in India*. U.S. Agency for International Development mission to India, New Delhi, India.

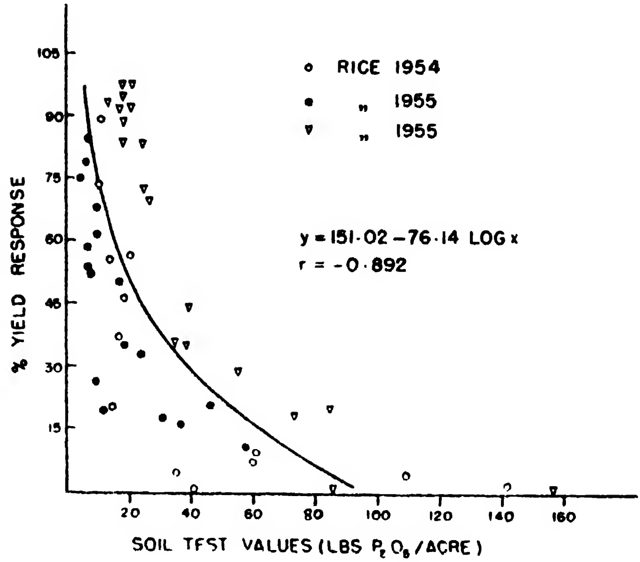

Fig. 18.8 Relationship between soil-test values for phosphorus by the Olsen's (0.5 M $NaHCO_3$) method and per cent dry matter yield response in greenhouse experiments on rice. *Source:* Muhr, G.R., et. al., *Soil Testing in India.* U.S. Agency for International Development Mission to India, New Delhi)

7, MICRONUTRIENTS

Is the fertiliser programme is intensified with respect to nitrogen, phosphate, and potassium, a greater withdrawal of other nutrients occurs from the soil by crop plants, resulting in new deficiencies. For example, a farmer using ammonium nitrate and triple superphosphate may one day expect a deficiency of sulphur. Fruit plants which grow on the same site for many years, may also respond to micronutrient applications. There is evidence to indicate that common field crops in certain localities respond to micronutrient applications (Chapter 16).

Soil analysis data in India and Pakistan also show that manganese and copper may be limiting crop yields in certain areas. In Madhya Pradesh, India, about 11 per cent of the soil samples had less than 3 ppm. available manganese (water soluble + exchangeable). Sherman and Harmer (1943) have suggested 3 ppm. available manganese plus 100 ppm. reducible manganese as the critical limit below which deficiency conditions may exist. Bondorff (1956) has given the limit of available manganese showing the probability a manganese deficiency (Table 18.7). The need for determining the micronutrient status in soils, calibration of soil tests with crop response and the determination of critical limits of deficiency and toxicity in soil and plants are indicated. Presently the facilities for micronutrient analysis are limited to only a few laboratories in Tropical Asia.

TABLE 18.7
MANGANESE INDEX AND PROBABILITY OF MANGANESE DEFICIENCY

Manganese Index	Percentage of observed deficiency
0.0–0.5	95
0.6–1.0	64
1.1–1.5	44
1.6–2.0	39
2.1–2.5	28
above 2.5	6

One unit of manganese index = 0.1 mg of exchangeable Mn per 100 gm of soil.
= 1 ppm Mn = 2.5 Kg Mn per hectare.

Source : Bondorff, K.A. *Soil Testing Results, their Interpretation and Application.* 1956.

8. SALINITY AND ALKALINITY

India and Pakistan have considerable irrigation potential, but irrigation is a mixed blessing. Initially it greatly increases crop yields, but there is a great hazard of using too much water because the charge for water is not on a volume basis. Canal irrigation in particular is fraught with certain dangers. Irrigation has increased and so has the salinity and alkalinity problem because of seepage from the canals. In other areas where irrigation is practised, the water table has shown a tendency to rise because of improper use. It is imperative that the irrigation engineers and the soil scientists coordinate their efforts to keep strict watch on the subsoil water level and devise means to develop adequate drainage before the soil is permanently damaged by salinity or alkalinity.

9. BACTERIAL FERTILISERS

The role of certain microorganisms like *Aspergillus niger* and *Azotobacter* species in detecting soil deficiencies has been discussed in Chapter 17. It should be emphasized that soil microbiology has not received the attention it deserves in Tropical Asian countries. Certain fundamental microbiological properties would be a great help toward creating fertile conditions. Not all soils have the same nitrogen fixing or nitrification capacity. This can be due to efficient strains of organisms and/or particular soil conditions. The use of artificial inoculation of legume bacteria for increasing crop yields is well known but the supply of proper cultures for all leguminous crops should be made more readily available to all

farmers in Tropical Asia. The isolation and inoculation of proper strains of *Azotobacter*, blue-green algae, or phosphate solubilizing bacteria offer challenging opportunity in improvement of soil fertility, To be successful, artifical inoculation presupposes that proper conditions for the survival and growth of the bacteria have been provided in the soil.

10. EFFECT OF FERTILISERS ON CROP QUALITY

Improper use of fertilisers, including improper balance of nutrients, is not only wasteful but can be deleterious to the crop yields and crop quality. Crop quality is not easy to determine but it is influenced by the vitamin, mineral, protein, amino acid, and sugar content of the plant. Excessive nitrogen can decrease the phosphate content in leaves and in the grain. Vitamin content is also known to vary due to fertiliser treatments. Crop composition changes at various stages of growth in response to the application of fertilisers. It is especially important that crops contain adequate protein and minerals for animals and man, but not much attention has been given to the nutritional qualities of crops in Tropical Asia.

11. COORDINATED APPROACH TO SOIL-FERTILISER RESEARCH

The research in many Tropical Asian countries is often confined to a particular department or section, resulting in data which finds limited application to the problems of the farmers in increasing crop yields. For example, many agronomical experiments are done without soil and plant analysis. The diseased condition of a plant is often investigated by the soil scientist or the plant pathologist but rarely by *both* specialists working as a team. This results in a different and often inaccurate interpretation of results. In the absence of a coordinated approach, many results are difficult to explain and there is duplication of effort on the part of different specialists. Many agricultural problems need to be tackled from more than one angle. The cooperation of different specialists would go a long way in producing high quality research for the purpose of assisting farmers in the developing countries in Tropical Asia.

Many more problems deserve our attention such as soil-moisture conservation research, plant population studies, rotational and manuring studies, lime requirement of acid soils, and water requirements of crops. All such studies would be more highly rewarding with a coordinated approach.

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APPENDIX

APPENDIX A

Detailed Description of the Various Soils Delineated in the Revised Soil Map of India

(See Soil Map of India, Page 118)

The Red soils or the Red earths occur in India mainly in the Peninsular portion in the South and along the east coast going up to Assam in the north-east. Parts of east-central India also have the red soils. These soils vary considerably in texture, some being sandy, while a great many are loams of different kinds and a few are clay soils. The two predominant types that have been distinguished for purposes of delineation in the Soil Map of India are the Red loams and the Red sandy soils, and this differentiation also seems to be related to their genesis from geological materials of distinct compositional differences. In general, the Red soils as they occur in Peninsular India are derived from granites and gneisses, mainly of the Archaean period. The other rock formations from which Red soils are developed are sandstones, hornblende, mica schists, acid traps, quartzites and shales.

1. RED LOAMY SOILS

The red loamy soils in particular are formed by the weathering of the rocks like gneisses, charnockites, diorites and others which are relatively richer in the clay-forming minerals and correspondingly poorer in silica, the acid component. The weathering of the feldspars, micas, hornblende or other base-rich minerals results in formation of fine textured soils where free silica to form the sand component is relatively less abundant. In some Red soils, lime concretions in the form of nodules or thick veins are found to occur. The latter result from the weathering of the feldspars containing lime in the rocks which occur as intrusions in the surrounding rock mass. The texture of these soils may vary from loam to silty clay

and clay. The normal red loamy soils have a pH around neutrality or else slightly on the acid side while the soils containing lime may show a pH 8.5. The A of horizon which may have a depth ranging from 25 to 40 cms is a dark reddish brown (5YR 3/2) loam with a crumb structure and the B horizon going down to 70 to 80 cms. from the surface may have a dark brown (7.5 YR 3/2) loam or clay loam with weak angular blocky structure. Below this layer is met soft disintegrating weathered gneissic rock, and in the case of lime-bearing rocks there may be thick veins or beddings of soft and hard calcareous deposits resulting from the weathering of the lime-rich feldspathic gneiss. In such lime bearing soils the B and occasionally the A horizon also may have lime-concretions of varying sizes distributed in them.

2. RED SANDY SOILS

These soils are generally derived from granites, coarse grained granites, quartzites, sandstones, etc., and are characterised by being rich in the fine and coarse sand fractions. The clay minerals become coated with red hematite or yellow limonite or a mixture of two oxides of iron forming a red, yellow or reddish yellow soil. The yellowish soil becomes red when the limonite undergoes dehydration and changes to hematite. Ferruginous gravel formed of impure iron, alumina and silica concretions and bits of quartz are the common accessory constituents of Red soils. The characteristic clay minerals present in these soils is of the kaolinitic type and exchange capacity of this is about 0.25 to 0.5 m.e. per gram of clay. The base exchange capacity of the soils generally varies from 5 to 25 m.e. per 100 grams, depending upon the amounts of clay and organic matter. The majority of these soils are slightly on the acid side with a pH ranging from 4.5 to 6.5 while a few may have a pH on the alkaline side.

The red sandy soils have a moderately deep A horizon of pale reddish brown and red with textures varying from fine sand through loamy sand to coarse sand. The B horizon is dark reddish brown loam or sandy clay loam of varying depths. The depth may vary from 15 cms to 30 cms and over. The C horizon is a weathered parent material of disintegrating coarse grained granite or granatoid gneiss. This material may retain the morphology of the rock structure to a considerable extent, but crumbles under pressure. The texture may vary from gritty coarse sandy clay to gravelly loam. Considerable amounts of coarse angular silica grits remaining from the weathering of the parent rock may be present.

3. LATERITE SOILS

Laterite is generally reddish or yellowish-red in colour and often has a vermicular structure. The formation may be massive and firm or is may be in the form of loose aggregates of a nodular ferruginous mass. If the formation is massive and if the moisture conditions and consistence are satisfactory, laterite may be quarried and cut into blocks of the size of large bricks and on exposure dehydrate and become as hard as granite. Such material is quarried for use as bricks for building purposes. The material in fact derives its name from the Latin term "later" meaning brick. Laterites are believed to be formed from the weathering of certain types of rocks of a basic nature, possibly under conditions of high rainfall which permits rapid leaching and removal of soluble basic constituents. The gradual removal of silica under favourable conditions obviously leaves behind the matrix rich in iron and aluminium oxides and hydroxides and some silica.

Lateritic soils are those associated with and are derived from laterites. The decomposition of only a part of the colloidal complex is presumed to have taken place and there is a large proportion of the primary kaolinitic minerals than in laterites. As the laterites do not contain primary clay minerals, they show the typical properties of clay such as plasticity cohesion, shrinkage, expansion, and base exchange properties only to a small extent. The base exchange capacity of the mineral colloids may range from 2 to 4 m. e. per 100 grams for laterites and from 4 to 7 for lateritic soils. The molecular silica to sesquioxide ratio of laterite soils is below 1.35.

The soils are in some cases deep but in many areas rather shallow.

4. RED AND YELLOW SOILS

In the east central and north east central parts of India occur soils which are characteristically yellow in colour. The range of colour may shade from reddish yellow to yellowish brown and the soils are usually fine textured. In some cases these soils are associated with soils developed from laterites or overlying laterites. Otherwise they are derived from a variety of rocks underlying in the profile at depth varying from 100 to 200 cms. Micaceous quartzite schists, phyllites, horneblende schists and gneisses, are some of the rocks giving rise to these yellow soils. While in some cases poor drainage conditions may be the cause for the yellow colour, the yellow colour of the surface soils cannot be due to this and

the soils in general are fairly well drained. The soils have a pH around neutrality or else slightly on the acid side, and it is a moot point if these soils can qualify to be called Red-Yellow Podzolic soils, after those described in south-eastern United States.

The A horizon of these soils is loam to silty loam in texture and are moderately rich in humus. These soils possess a textural B horizon with colour of high chroma which are usually yellow, but at times red. This horizon has a blocky structure and at times exhibits considerable shrinkage and cracking on drying. Mottlings and pigmentation due to soft nodular iron may be found in this horizon. In lands cultivated for paddy, a gleyed B horizon may be found at depths varying from 100 to 150 cms.

5. BLACK SOILS

Soils with a characteristically dark colour ranging from dark brown to deep black, occur extensively in the central and south-central parts of India. These have been classified for purposes of mapping in a broad manner into different groups based upon the depth of their formation. Soils possessing depth ranging from 30 to 50 cms are described as shallow black soils, those having depth ranges from 50 to 120 cms as medium black soils, and those with depth in excess of 120 cms. and going down to 200 cms. and over as deep black soils.

As a group these soils are fine-textured and their clay content varies from 40 to 60%. They are plastic and sticky when wet and very hard when dry. The composition of the clays is generally of the montmorillonitic group and as a result show very strong swelling and severe shrinkage with changing moisture conditions, causing heavy fissuring and deep cracking on drying. Because of the physical movement of the surface soil to the subsurface layers through the fissures. these soils are popularly described as "self mulching" or "self ploughing" soils.

6. SHALLOW BLACK SOILS

These are black soils derived from basalts of the Deccan traps. The soil is usually silty loam to clay in texture, and the surface has a colour ranging from dark brown to dark yellowish brown. The structure is granular or else weakly Bocky. Lime in the form of fine grains or nodules is usually present and the soil is freely drained. The solum rapidly merges with the disintegrating hard basaltic parent rock.

7. MEDIUM BLACK SOILS

These are black soils with depths ranging from 50 to 120 cms. and developed from a variety of rocks including basaltic traps, Dharwar schists, basic granites, gneisses, hornblende and Chlorite schists. The texture ranges from silty clay to clay and it is difficult to notice any increase in the clay content in the lower horizons. The soils are moderately rich in organic matter and fairly well drained. While these soils contain lime in varying proportions, some of them may have thick layers of clacareous nodules (20 to 30 cms. thick) in the Cca horizon. Further differentiation between these soils as they occur in Peninsular India is possible on the basis of the occurrence of gypsum or its absence in the subsurface layers. Where gypsum occurs it is generally found below the third foot and is associated with a high concentration of soluble salts, particularly sodium and magnesium sulphates The gypsum occurrence, which is in pockets of crystalline masses, is usually over the lime-bearing strata.

8. DEEP BLACK SOILS

These are soils with depth in excess of 120 cms. and going down to 200 cms. and over. These are derived from basaltic traps and represent a large part of the black soils of the Deccan plateau, commonly identified as the "Regur" soils. Because cotton is the important commercial crop grown on these soils, these are also referred to popularly as the "Black Cotton Soils".

The texture of the surface and subsurface layers is more or less uniform and silty clay to clay. The percentage of clay may vary from 40 to 60% and over. Distribution of lime in the form of irregular shaped nodules of varying sizes, may be uniform throughout the profile with heavier accumulations at depths of over 150 cms. The soil reaction is moderately alkaline (pH 8.0 to 8.5). In common with the other black soils, the clay mineral is of the 2 : 1 lattice structure and possess high retentivity for moisture. In areas of low rainfall of 15 to 20 inches annually, the practice of "dry farming" operations helps to conserve the moisture and raise a crop successfully. The presence of soluble salts in the subsurface layers is usually the cause for deterioration in the structure of the soil and creation of difficulties in cultivation, after introduction of irrigation in areas where this is possible.

9. MIXED RED AND BLACK SOILS

The occurrence of red and black coloured soils side by side in areas of varying sizes and unpredictable patterns is a fairly common feature in transitional areas where either of these soils are found. In view of the difficulty of separating out of the location of the individual soils in the soil map, these soils have been grouped as a category of the mixed soils. In many cases in an area of predominantly red soils, while the red soils occur in terrain of elevated topographic features, the black soils may be found in the lower topographic levels. The higher moisture regime and the accumulation of organic matter in the lower levels tend to form a darker coloured soil of finer texture. The greater mobility of the montmorillonitic clay may also be a factor in assisting the accumulation of these black soils in the lower levels. In certain cases intrusions of basic rocks, in the midist of a predominantly granitic and granatoid gneissic area of red soils with the kaolinitic type of clay, have resulted in formation of patches of black soil. Basic rocks rich in soda lime feldspars and a variety of schistose materials give rise to formations of black soils in such conditions. In these cases it is a matter of common observation that the black soils occur on higher topographic features in relation to the red soils.

Conversely, in areas of predominately Black Soils, occurrence of patches of red soil are not of unusual occurrence. In such cases field observations indicate that the black soils overly the red soils, the former having been formed from a variety of parent rocks of different composition from those of the red soils. Flows of basalts, trap, and even extensive intrusions of basic rocks, are found to give rise to such a feature. The black soils being composed of fine clay are naturally more impervious to drainage and consequently more erosive and these invariably spread over the adjoining red soils of varying shades, which are best described as a mixture of red and black soils.

10. ALLUVIAL SOILS

These soils are a very large group of soils formed by transportation by streams and rivers and deposition over the flood plains or along the coastal belt. The character of the soils vary a great deal and reflect the nature of soils that occur in the region of their transportation. Their colour, texture and quality accordingly vary and also their development in regard to profile differentiation. Most of the young alluvium show little or no horizonation, while the older alluvium show distinct profile development.

Their colour varies from pale grey and pale yellow to deep black soils and their texture can vary from coarse sand to fine clay. In view of the extremes of variation that are possible in these soils and the large variation in their agricultural potentiality, it has been found convenient to divide this large groups of soils into separate groups to distinguish these characteristics.

11. COASTAL ALLUVIUM

Soils of the coastal belt all along the peninsular region and extending for varying widths between the sea and the range of hills along the east and the west coasts, are characterised by being relatively recent desposits of fluvial origin. The texture of these soils are extremely variable and may range from being sandy to silty clay and clay, depending upon the nature of the deposits. Excepting in the older deposits, these soils do not show a prominent horizonal differentiation. The soils are usually deep and the colour may range from bright reddish brown and yellowish brown to grey and dark grey. The soils being fertile and occurring as they do in the belt of both the southeast and northwest monsoon rains, paddy is cultivated intensively in these areas.

The composition and mineralogy of these soils is greatly influenced by the predominant soils and parent materials of the catchment areas. Alluvial soils derived from calcareous materials are usually composed of dark coloured fine clay, while in areas where the red soils from the granitic and granitc gneissic rocks are dominant, the alluvial soils are poorer, often medium or coarse textured and relatively richer in kaolinitic clays. Frequently, these soils in areas which are not much above the sea level get inundated by sea water and suffer from all the problems of salinity.

12. COASTAL SAND

Characteristically in certain areas along the coast for varying widths in the peninsular region, occur soils which are sandy, deep, and lacking in any profile or soil development. The lack of profile development is attributable to the coarse nature of the parent material. These sandy stretches can be considered to be Regosols. The topography of the sandy regosols varies from flat to gently undulating, with occasional dunes. Salinity is rarely a problem in these areas because of the relatively low watertable and the free drainage. Some areas in the lowlying flat lands can be marshy and saline, in which case the swampy condition makes the areas unfit for

any useful cultivation. These sandy stretches, if the ground water level is not too deep, are used for raising fuel trees, particularly Casuarina, besides coconut. When cultivated, the areas of old red sands, particularly if they contain some clay, are used for raising millets and also seedlings of tobacco and vegetables which are transplanted and grown on finer textured soils in nearby areas.

13. DELTAIC ALLUVIUM

The soils of the Deltaic alluvium represent the heterogeneous types of sediments brought by rivers and deposited at the mouth of the great rivers. The east coast of Peninsular India is characterised by the formation of deltas at the mouth of the major rivers of the subcontinent that flow into the sea. Of these rivers the Ganges and the Brahmaputra flow from the Himalayas and drain the extensive plains of northern India ; the Mahanadi, the Godavari and Krishna, the Deccan Plateau and the Central India plains ; while the Cauvery drains the southern part of the peninsula. These rivers carrying the alluvium of the extensive areas they traverse, deposit them at the regions where they join the sea, and these deposits form the alluvial soils of these deltas.

The materials from which alluvial soils of the different deltas are formed vary considerably both in composition and in texture. In the great flood plains, the material is mainly clayey, sometimes loamy and sporadically sandy. The Gangetic alluvium reflects the characteristics of the region the river flows through, viz., the great alluvial plains of North India. The soils are light coloured silty and silty clay. The Mahanadi delta alluvium again are light brown and light yellow in colour and in texture, silty loams, loams and sandy loams. These reflect to a large measure the colour and texture of the soils of the east central plateau of Madhya Pradesh and Orissa States through which this river and its tributaries traverse. The Godavari and Krishna rivers, draining as they do the black soils derived from the basalt traps, are largely composed of dark coloured fine textured silty clays and clays. They also reflect the base-rich characteristics of the rock material which have given rise to the black soils of the Deccan plateau. The alluvium of Cauvery Delta, while not truly representing the red sandy and coarse textured soils of the granitic area through which most of the river's course lies, contain a high proportion of dark coloured silty and silty clay soils.

The drainage conditions of most of the Deltaic soils, other than the Gangetic alluvium, are satisfactory and hence show rarely grey or mottled

horizons at the deeper layers. The accumulation of organic matter in the A horizon vary a great deal and reflect the drainage and cultivation conditions of the respective areas. Thus the Gangetic alluvium at the mouth of the Ganges which is largely swampy, shows considerable accumulation of organic matter, the natural vegetation being mangrove and such species, while the other alluvium which are extensively cultivated and cropped show much less accumulation of organic matter.

14. ALLUVIAL SOILS

These soils represent the vast tracts of riverine alluvium of the Indo-Gangetic plain. The deposits of the great rivers : the Jumna, the Ganges, and their tributaries the Gandak, Gomti, Ghagra and others, which flow out of the Himalayan ranges, have accumulated over long periods in the northern part of the sub-continent. The area stretches for a length of nearly 1000 miles in an east to west direction and a width of about 200 miles and is characterised by a topography which is monotonously level and with a general gradient of about 1% from the north west to the south east. The depth of the alluvium is great and may extend to many scores of feet, though in some places it may be shallow. These water deposited sediments are in a large measure old, though newer deposits are continuously being made, particularly in the areas adjacent to the river courses.

The colour of the soils range from pale grey through yellow and yellow brown to dark grey. The texture is generally silty, though loams and silty clay loam soils are not infrequently met with. A well formed B horizon possessing strong angular blocky structure is met with, but in areas where accumulation of soluble salt has taken place this may not be prominent. Deposition of lime in the B_3 horizon which might result in strong cementation is frequently met with. These soils if not badly affected by salts or suffering from drainage impedence, are fertile and respond well to manuring. Wheat, gram and oilseed crops are commonly grown, while paddy is also grown in the eastern parts of the region.

15. CALCAREOUS ALLUVIAL SOILS

These are alluvial soils which occur characteristically along the north eastern districts of Uttar Pradesh and extending to the north western parts of Bihar. The calcareous soils have developed on the alluvium brought by the river Gandak flowing from the Himalayas in a north-west to south-east direction towards the Ganges. The main characteristics of the soil

is the high content of $CaCO_3$ (10 to 40%) which is distributed throughout the depth of the profile. The soils are light coloured, being pale brown and yellow brown, lack in horizonal differentiation, and the texture varies from sandy loam to loam. The pH of the soils are on the alkaline side and the contents of available phosphoric acid and potash are low. The soils are zonal in character.

16. CHESTNUT BROWN SOILS

These soils also come under the broad group of alluvial soils. The old Indo-Gangetic alluvium of the north-west region of India has been subject to varying climatic conditions from humid to arid, as the distance from the Himalayas increases. Thus the State of Punjab, where this region lies, has been divided into six climatic zones representing the extremes mentioned above. The soils within the sub-humid climatic zone have attained profile characteristics referred to as the Chestnut Brown soils. These soils, in common with the other alluvial soils of this area, are deep and the soils are clayey with clear evidence of mechanical illuviation in the middle horizons. There is clear indication of the movement of $CaCO_3$ throughout the profile and a layer of $CaCO_3$ accumulation is reached below 5 feet. The pH of the soil is neutral to slightly alkaline, and the predominant clay mineral is of the 2 : 1 lattice type. The soils are deficient in phosphate, with medium status in organic matter and nitrogen.

17. GRAY BROWN SOILS

These soils have developed under semi-arid conditions. The texture of the soils is usually coarse, being usually sandy loam with a preponderance of coarse sand. There is evidence of mechanical eluviation, the B horizons being distinctly finer textured. $CaCO_3$ is present throughout the depth of the profile with $CaCO_3$ layeration being found fairly near the surface 2 to 3 feet. The predominant base in the exchange complex is Ca. The soils are neutral to alkaline in reaction and the clay mineral is predominantly montmorillonite. The soils are generally poor in nitrogen and phosphorus, but are adequate in respect of potash.

18. DESERT SOILS

The soils are found characteristically in the arid zone in the north western region in the States of Rajasthan and the Punjab and lying between the

Indus River on the west and the Aravalli Range of Hills on the east, are described as Desert soils. They are Regosols on wind, blown sand and sand dunes. These are coarse textured and derived from the disintegration of rocks in the adjacent areas and blown in from the coastal region and the Indus valley.

These soils are composed of sand to a depth extending beyond 50 cms. Their A horizon is weakly developed or absent as on shifting sand dunes. The soils show no or only a weak B horizon. Regosols on young dunes are usually yellowish-brown to very pale brown in colour and may contain considerable amounts of weatherable minerals.

Some of these soils contain a high percentage of soluble salts in the lower horizons. They possess fairly high pH and varying amounts of $CaCO_3$. They are low in organic matter.

19. TERAI SOILS

The soils of the Terai region lying at the foot of the Himalayan ranges possess certain characteristics of their own, which makes it necessary to denote them separately on the soil map. These occur all along the foothills in the northern parts of Uttar Pradesh, Bihar and West Bengal, and are fairly deep, moderately fertile soils. There is considerable evidence that these soils were deposited as a result of their movement through water erosion of the Himalayan ranges. Lime in the form of fine nodules occurs in these soils in some areas. The surface soils possess a sandy loam or silty loam texture and the illuviation of the finer particles into the B horizon is marked. The lower strata are however formed of water-worn rounded stones and gravels of miscellaneous rock moved down from the hill ranges. The layers of the rounded stones may extend for depths varying from 100 cms. to over 300 cms. from the surface and contain different proportions of the soil material. These layers of stones make the soils permeable, but the natural formation of these soils at the foot of the hills where, due to high moisture regime and continual seepage of water from the hill ranges, the lands are subject to water-logging. The excessive soil moisture and the fertility of the soil have caused excessive growth of rank vegetation and weeds, but once drainage is improved and cultivation adopted, the soils become highly productive.

20. BROWN HILL SOILS

These soils occur often in hilly regions and under moderately heavy vegetation. The soils are formed over a variety of parent rocks, but in the

sub-Himalayan region where they are characteristically located, this material is sandstones, grey micaceous sandstones, and shales. The original vegetation was mainly coniferous, and the soils have developed to their present condition after the removal of the original vegetation. They form a system of low foothills corresponding to the Shivalik ranges and are composed enitrely of Tertiary and principally of the upper Tertiary formations. The rainfall in the region of their occurrence is moderately high and in the range of 40″ to 70″ per annum. The surface soils are dark brown in colour and loam to silty clay loam in texture and moderately rich in organic matter. The B horizon is fairly deep and of 50 to 80 cms. depth, with texture in the silty loam to clay range, and compact. These horizons are lacking in free lime and have a pH around neutrality and slightly on the acid side. The lower horizons below 100 cms, and extending to 200 cms. and over are slightly acid (pH 6.0 to 6.5) and composed of compact grey and dark brown clay loam. Below this layer are the weathered parent material from sandstones and shales.

21. SUB-MONTANE SOILS

These are soils found in the Sub-Himalayan region under forest vegetation of the coniferous type. The natural vegetation may consist of deodar (*Cedrus deodar*), spruce (*Picea morinuda*), blue pine (*Pinus excelsa*) and chir (*Pinus longifolia*). The rock types are of the usual varieties of hard and soft standstones and shales characteristically occurring in the upper Himalayan regions. The rainfall is usually high, being in the region of 70″ to 100″ per annum and the accumulation of organic matter in the surface layers and the lack of free lime could qualify these soil to be grouped under the Brown Podzol soils. The top surface layer, which may extend from 10 to 15 cms., is of dark brown and black sandy loam with loose undecomposed organic matter. The next layer extending to a depth of 50 cms. is a dark brown sandy clay loam rich in humus. The pH of both these layers is in the region of 5.0. The next layer to a depth of 15 cms. is of a lighter colour, representing eluviation, and below this the layer going to depth of about 100 cms. is brown and reddish brown, compact sandy clay. The lower layers are mixed with the weathered gravel of the parent materials of sandstones and hard shales. The pH of all the horizons are on the acid side and free lime is absent. Analysis of these soils indicate that the top layers are siliceous in nature, that there is an illuviation of sesquioxides at a depth of about 60 cms., and that calcium is conspicuously absent from the profile.

22. MOUNTAIN MEADOW SOILS

High up in the Himalayan region at elevations about where trees do not grow, and also on the slopes with a southern aspect at lower elevations, exist soils of moderately shallow depth developed from the sandstone and shales. The soils, because of their relatively thin formation and the poor profile development, may also be considered as skeletal soils of the Himalayas. The vegetation is mainly grass and the growth of the grass helps to afford the binding material to prevent the loss of soil through wind and snow action. The built up of organic matter from the grass roots is assisted by the relatively low temperatures prevailing in the region. The soils in the nature of their formation vary a great deal in their texture and structure, being admixed with varying proportions of the partly weathered gravel and rock pieces of the sandstone and shaly material.

23. SALINE AND ALKALI SOILS

Saline soils represent the group of soils that are characterised by the occurrence of a high proportion of soluble salts, usually the chlorides and sulphates of the alkali bases. These can occur in a variety of soils and are found among the groups of Red, Black and Alluvial soils. No differentiation between these different groups is attempted in the map and the saline soils demarcated in the map reflect the other general characters of the soils predominantly occurring in the vicinity. In a number of cases, as in the case of soils occurring close to the sea, the salinity is due to the action of sea water and salts therefrom. In other cases, the enhanced salinity is due to the removal of salts from soils in higher topographic situations and their accumulation in low lying areas. This kind of feature is fairly common in undulating land over which red soils occur. In the case of the areas of black soils, the soluble salts usually occur in a strata below the surface, and the introduction of irrigation or other causes whereby the water table is raised, causes the general rise of salts to the surface levels. In the areas of alluvial soils, as in the Gangetic Plain, the lack of drainage causes a general rise of the soluble salts to the surface, which occur as a thick inflorescence on the surface layers. The electrical conductivity of these soils will be over 4 mmhos and their pH in the region of 8.0 to 8.50.

The soils affected by alkali have a high pH, which may range between 9.0 and 10.5, and the exchangeable sodium may be over 15% of the total exchange capacity. In these cases the physical condition of the soils is also affected.

24. PEATY AND PEATYS-ALINE SOILS

The peaty-saline soils are developed from brackish water sediments and contain sulphides which are principally of pyrite (FeS_2). These may also be classed as very acid alluvial soils and they occur in areas of Kerala State in the south-western tip of the Indian peninsula. They are located at the junction of the hill streams flowing from the western coastal range of hills and the backwaters of the sea. When not drained, their pH may be only slightly acid. Upon drainage, oxidation and hydrolysis of the sulphur compounds contained therein, sulphuric acid in varying amounts is formed and the pH goes down to between 3 and 4, and in extreme cases a pH of 2.0 is not unusual. This characteristic may occur in some layer or else throughout the profile. Another important characteristic of these soils is their high content of free aluminium and also iron, which are likely formed by the breakdown of the clay through action of sulphuric acid. Accumulation of organic matter in layers of peaty matter also result as a consequence of the lack of oxidation and the poor drainage condition.

Small areas of peat accumulation at the surface occur in the northern parts of Bihar and they are characterised by the presence of a high amount of organic matter, low base saturation and low pH.

25. SKELETAL SOILS

The skeletal soils are so designated because of the thickness of the soil and the lack of characteristics of profile development in them. Such soils usually occur formed over sandstones of the Vindhayn formation. The soils are coloured pale brown to dark brown and may have thickness varying from 7 to 15 cms in thickness excepting in hollows between the rocks and in positions sheltered from erosion, where they may be thicker. The soils are easily disturbed through erosion and in consequence the development of any horizonation is hardly noticeable. The texture of the soils is usually sandy loam to loam and reflect the origin of the soils from highly siliceous rocks. In other areas where granite and other igneous rocks have given rise to skeletal soils, the reason for the formation of the thin soils is attributable to the resistance of the minerals in the rocks to weathering and the balance between disturbance through erosion and soil formation. The poor nutrient supply from such soils sustain only a hardy type of natural vegetation, and the soils have low value for cultivated crops.

The skeletal soils in the Himalayan and Ladakh regions are composed of thin soils overlying fragmented sandstone and shale material. The low rainfall, the poor vegetation, the lack of cover, and the existence of conditions unfavourable for intensive weathering have militated against development of deep soils. The factors of wind erosion have also left their imprint by the removal of even the thin soil formed on them, so that in a great measure the rock material remains exposed on the surface.

Weights, Measures and Conversion Factors

GENERAL

Area

1 hectare	= 2.47109 acres	1 acre	= 0.40468 hectare
1 square kilometre	= 0.38610 square mile	1 square mile	= 2.5900 square kilometres
1 square kilometre	= 100 hectares	1 square mile	= 640 acres = 259 hectares

Yield

100 kg per hectare	= 1.4869 bushel (60 lbs) per acre	1 bushel (60 lbs) per acre	= 67.253 kg per hectare

Liquid measure

1 litre	= 0.26418 gallon	1 U.S. gallon	= 3.78533 litres
1 hectolitre	= 0.21997 imp. gallon	1 imp. gallon	= 4.54596 litres
	= 100 litres	1 gallon	= 4 quarts

Weight

1 kilogram	= 2.20462 pounds	1 pounds	= 0.45359 kilogram
1 metric ton	= 0.98421 long ton	1 long ton	= 1.01605 metric ton
1 metric ton	= 1.10231 short ton	1 short ton	= 0.90718 metric ton
1 metric ton	= 1,000 kilograms	1 long ton	= 2,240 pounds
1 metric quintal	= 100 kilograms	1 short ton	= 2,000 pounds

1 m. t. = 19.684 cwt (112 lb)	1 cwt (112 lb)	= 0.050802 m. t.	United Kingdom and British territories
1 m. t. = 22.046 cwt (100 lb)	1 cwt (100 lb)	= 0.045359 m. t.	Canada, United States
1 m. t. = 66.667 metric arrobas	1 metric arroba	= 0.015 m. t.	Brazil
1 m. t. = 21.739 Spanish quintals	1 Spanish quintal	= 0.046 m. t.	Chile, Costa Rica, El Salvador, Guatemala, Philippines, Spain, Venezuela
1 m. t. = 21.735 Spanish quintals	1 Spanish quintal (100 libras)	= 0.046009 m. t	Cuba, Honduras, Peru
1 m. t. = 22.258 kantars	1 kantars	= 0.044928 m. t.	Sudan, United Arab Republic
1 m. t. = 26.792 maunds	1 maund (Standard) (82.286 lb)	= 0.037324 m. t.	India, Pakistan
1 m. t. = 266.67 kwan	1 kwan	= 0.00375 m. t.	Japan, Korea, Rep. of
1 m. t. = 16.667 piculs (pikuls)	1 picul (pikul)	= 0.060 m. t.	Cambodia, Laos, Thailand,
1 m. t. = 16.538 piculs (pikuls)	1 picul (pikul)	= 0.06048 m. t.	Brunei, Federation of Malaya, Hong Kong, Macau, North Borneo, Sarawak, Singapore

FACTORS FOR DIRECT CONVERSION

The following factors are provided for the purpose of converting weights per unit of area and weights per unit of volume from the British to the metric system :

1 cwt per acre	=	125.54	kilograms per hectare
1 long ton per acre	=	2510.175	kilograms per hectare
1 lb per quarter	=	0.1559	kilograms per hectolitre
1 lb per gallon	=	0.0998	kilogram per litre
1 lb per bushel	=	1.2472	kilograms per hectolitre

**Source* : Vol. 16, Production Yearbook, 1962, F.A O., Rome, Italy.

Glossary

A

A Horizon. (*see* Soil Horizon).

ABC Soil. A soil with a distinctly developed profile, including an A, B. and C horizon.

AC Soil. A soil having a profile containing only A and C horizons and no clearly developed B horizon.

Accelerated Erosion. Erosion more rapid than natural, normal, or geological erosion, resulting from the activities of man or animals.

Acid Soil. A soil giving an acid reaction (below pH 7.0).

Acidity, Active. The activity of hydrogen ion in the aqueous phase of a soil. Its activity is measured and expressed as a pH value.

Acidity, Free. The titratable acidity in the aqueous phase of a soil.

Acidity, Potential. The amount of exchangeable hydrogen ions in a soil that can be rendered free or active in the soil solution by cationic exchange.

Actinomycetes. A general term to cover a group of organisms intermediate between the bacteria and the true fungi, usually producing a branched mycelium and which sporulate by segmentation of the entire mycelium or, more commonly, by segmentation of special terminal hyphae. Any organism belonging to the order *Actinomycetales*.

Adsorption Complex. The group of substances in soil which are capable of adsorbing materials. The organic matter and colloidal clay form the greater part of the adsorption complex; the materials in silt-and sand-size exhibit adsorption but to a greatly reduced extent in most soil material.

Aerate. To impregnate with a gas, usually air.

Aeration, Soil. The process by which air and other gases in the soil are renewed. The rate of soil aeration depends largely on the size and number of soil pores and on the amount of water clogging the pores.

Soil Science Society of America Proceedings (May-June 1962), 26, No. 3.

A soil with many large open pores to permit rapid aeration is said to be well aerated, while a poorly aerated soil either has few large pores or has most of its pores blocked by water.

Aeration Porosity. The proportion of the bulk volume of the soil that is filled with air when the moisture tension is at some specified value. The tension is usually specified in the range 40 to 100 cm. of water.

Aerobic. Living or active only in the presence of molecular oxygen. Pertaining to or induced by aerobic organisms, such as aerobic decomposition.

Air-dry. State of dryness after prolonged exposure to air, or any exposure sufficient to bring a material into moisture equilibrium with the air. Moisture content at air-dryness is indefinite, since it depends on relative humidity.

Alkali Claypan. A claypan containing 15 per cent or more exchangeable sodium.

Alkali Soil. An alkali soil which has either so high a degree of alkalinity (pH 8.5 or higher) or so high a percentage of exchangeable sodium (15 per cent or higher), or both, that the growth of most crop plants is reduced. Thus alkali soils, as a group, have a wide range of exchangeable sodium and pH. (*see* Sodic Soil; Salt-Affected Soil).

Alkaline Soil. Any soil that is alkaline in reaction. (*see* Reaction, Soil).

Alkalization. A process whereby the exchangeable sodium content of the soil is increased.

Alpha Humus. A mixture of indefinite composition of dark-colored organic substances precipitated upon making strongly acid a dilute alkali extract of soil.

Ammonia Fixation. Adsorption of ammonium ions by soils or minerals in such form that they are neither water-soluble nor readily exchangeable.

Ammonification. Production of ammonia as a result of the biological decomposition of organic nitrogen compounds.

Anaerobic. Living or active in the absence of molecular oxygen.

Angular Cobbly. (*see* Cobbly).

Antibiotic. An organic compound produced by microorganisms or higher plants which, in sufficient concentration, will kill or inhibit growth of certain other organisms.

Apparent Density (*Obsolete*). (*see* Bulk Density).

Apparent Specific Gravity (*Obsolete*). (*see* Bulk Specific Gravity).

Artificial Manure. (*see* Compost). In European usage, may denote commercial fertilisers.

Autochthonous Flora. The native microflora, commonly present in the soil in relatively constant numbers, presumed to subsist on the more

resistant soil organic matter and consequently little affected by the addition of fresh organic materials. Contrast with *zymogenic*.

Autotrophic. Capable of utilizing carbon dioxide as a source of carbon and of obtaining energy for the reduction of carbon dioxide and other life processes from the oxidation of inorganic elements or compounds, *e.g.*, sulphur, hydrogen, ammonium, and nitrite salts, or from light. Contrast with *heterotrophic*.

Azonal Soils. Soils without distinct genetic horizons. A soil order.

B

B Horizon. (*see* Soil Horizon).

Badlands. A land type nearly devoid of vegetation, especially a region where erosion has cut the land into an intricate maze of narrow ravines, sharp crests, and pinnacles.

Base Saturation. The extent to which a material is saturated with exchangeable cations other than hydrogen, expressed as a percentage of the cation-exchange capacity.

BC Soil. A soil profile having no A horizon.

Bedrock. The solid rock underlying soils and the regolith, or exposed at the surface without a cover.

Bench Terrace. Terrace with steep drop on the downhill side ; used on very steep slopes.

Biological Immobilization. (*see* Immobilization)

Biological Interchange. The interchange of elements between organic and inorganic states in a soil or other substrate through the agency of biological activity. It results from biological decomposition of organic compounds and the liberation of inorganic materials on one hand (mineralization), and the utilization of inorganic materials in the synthesis of microbial tissue on the other (immobilization). Both processes commonly proceed continuously in normal soils.

Biological Mineralization. The conversion of an element occurring in organic compounds to the inorganic form as a result of biological decomposition.

Biosequence. A sequence of soils whose properties are functionally related to differences in organisms as a soil-forming factor.

Bisect. A profile of plants and soil showing the roots and shoots in the normal position to give an indication of their vertical and lateral relations.

Black Earth. Used by some authors as synonymous with *Chernozem;* but by a few (in Australia) for self-mulching black clays.

Black Soils. A term used in Canada for soil with dark-colored surface horizons of the Black (Chernozem) zone; includes Black Earth or Chernozem, Wiesenboden, Solonetz, etc.

Bleicherde. The light-colored, leached A_2 horizon of the Podzol.

Bluff Podzol. (*see* Depression Podzol)

Bog Iron Ore. Impure ferruginous deposits developed in bogs or swamps by the oxidizing action of algae, bacteria, or the atmosphere on iron carried in solution.

Bottomland. (*see* Flood Plain)

Breccia. A rock composed of coarse, angular fragments cemented together.

Broad Base Terrace. A low, wide terrace used on gentle slopes.

Brown Earths. Soils with mull horizon and having no horizon of accumulation of clay or sesquioxides. Generally used as a synonym for Brown Forest soil but sometimes for similar soils which are acid in reaction.

Brunigra. (*see* Prairie Soils)

Buffer Compounds, Soil. The clay, organic matter, and such compounds as carbonates and phosphates, which enable the soil to resist appreciable change in pH value.

Bulk Density, Soil. Mass per unit bulk volume of soil that has been dried to constant weight at 105°C.

Bulk Specific Gravity. The ratio of the mass of a dry bulk volume of oven-dried (105°C.) soil to the mass of an equal volume of water.

Bulk Volume. The volume of an arbitrary soil mass including the volume of the solid particles and of the pores (interstices, voids).

Buried Soil. Soil usually covered by a deposit of considerable depth and usually greater than the thickness of the solum.

C

C Horizon. (*see* Soil Horizon)

Calcareous Soil. Soil containing sufficient calcium carbonate (often with magnesium carbonate) to effervesce visibly when treated with cold 0.1 N hydrochloric acid.

Calciphytes. Plants that require considerable amounts of calcium.

Caliche. (1) Layers near the surface more or less cemented by secondary carbonates of calcium or magnesium precipitated from the soil solution. They may be soft, thin soil horizons or hard, thick beds just beneath

the solum or exposed at the surface by erosion. (*see* Croute Calcaire) Not a geologic deposit. (2) Alluvium cemented with sodium nitrate, chloride, and other soluble salts in the nitrate deposits of Chile and Peru.

Capillary (Conductivity). (1) (Qualitative) The physical property relating to the readiness with which unsaurated soils transmit water. (2) (Quantitative) The ratio of the water-flow velocity to the driving force in unsaturated soil.

Capillary Potential. A number representing the work of moving a unit mass of water from the soil to an arbitrary reference location and energy state.

Carbon Cycle. The sequence of transformation undergone by carbon utilized by organisms wherein it is used by one organism, later liberated upon the death and decomposition of the organism, and returned to its original state to be reused by another organism.

Carbon Dioxide (CO_2) Evolution. The liberation of gaseous carbon dioxide from soil by biological processes.

Category. A subdivision in any field of knowledge. Any one of the subdivisions of the system of classification in which soils are grouped or arranged on the basis of their characteristics.

Catena. A sequence of soils from similar parent material and of similar age in areas of similar climates but whose characteristics differ owing to variations in relief and drainage. (*see* Toposequence).

Cation Exchange. The interchange between a cation in solution and another cation on the surface of a colloidal or other surface-active material.

Cation-Exchange Capacity. The sum total exchangeable cations adsorbed by a soil, expressed in milliequivalents per 100 g. of soil. Measured values of cation-exchange capacity depend somewhat on the method used for the determination.

Cemented. Having a brittle, hard consistence because of some cementing substance, such as calcium carbonate, silica oxides, iron and aluminum, or humus. The hardness and brittleness persist when wet.

Channery. (*see* Coarse Fragments)

Chasmophytes. Plants usually found in rock crevices.

Chemically Precipitated Phosphorus. Phosphorus compounds formed by reactions between constituents in solution into chemically homogenous particles of the solid phase.

Chemisorbed Phosphorus. A chemically precipitated monolayer on the surface of another crystalline species, formed by reaction of phosphorus compounds with solid-phase constituents. A form of sorbed phosphorus,

involving surface valence forces and chemical affinities between the phosphate ion and the lattice constitutents on which sorption takes place.

Cherty. (*see* Coarse Fragments)

Chiseling. Breaking or loosening compact soil or subsoil with a chisel cultivator.

Chroma. One of the three variables of color. The relative purity or strength (sometimes called *saturation*) of the spectral color. The chroma increases with increasing purity of the dominant wave length of light or decreasing grayness. (*see* Munsell Notation ; Hue ; Value)

Chronosequence. A sequence of soils whose properties are functionally related to time as a soil-formation factor.

Class. A group having a definite range in a property or attribute, such as acidity, slope, texture, structure, land capability, degree of erosion, or drainage of soils.

Classification. The assignment of objects or units to groups within a system of categories distinguished by their properties. In the classification of soils, the fundamental unit is a soil type. Similar soil types are grouped to form a series. Series are grouped into families, families into great soil groups, these into suborders and suborders into orders (of which there are three : the Zonal; Azonal, and Intrazonal).

Clay. (1) A soil separate. (*see* Soil Separates) (2) A textural class. (*see* Soil Texture)

Clayey. Includes all clay textural classes, *i.e.*, sandy clay, silty clay, and clay.

Clay Loam. A textural class. (*see* Soil Texture)

Claypan. Dense subsoil, horizon high in clay content, having a sharply defined upper boundary, and formed by downward movement of clay or by synthesis of clay in place during soil formation. The soil permeability is usually low in these claypans, but bulk density may not be appreciably different from that in the horizons below. (*see* Alkali Claypan ; Sodium Claypan)

Climatic Index. A number which condenses climatic data into a simplified expression. (Transeau's ratio : P/E is a climatic index)

Climax. A plant community of the most advanced type that is capable of development under the prevailing climatic conditions.

Climosequence. A sequence of soils whose properties are functionally related to climate as a soil-formation factor.

Clinosequence. A sequence of soils whose properties are functionally related to the amount of slope on which they were formed.

Coarse Fragments. Masses of mineral or rock material greater than 2 mm. in diameter.

Coarse Sand. (*see* Soil Separates ; Soil Texture)

Coarse Texture. In the United States, includes the sands, loamy sands, and sandy loams, except the very fine sandy loam, textural classes. Sometimes subdivided into sandy and moderately coarse textured. (*see* Sandy ; Moderately Coarse Textured)

Cobbles. Rounded mineral or rock fragments between three and 10 inches in diameter. (*see* Coarse Fragments)

Cobbly. Soils having rounded or partially rounded fragments of rock ranging from three to 10 inches in diameter. *Angular cobbly*, formerly included as stony, is similar to cobbly except that the fragments are not rounded. A single piece of either is a cobblestone or small stone. (*see* Coarse Fragments)

Colluvium. Deposit of rock fragments and soil material accumulated at the base of steep slopes by gravitational action. (*see* Creep)

Color. (*see* Munsell Notation)

Columnar Soil Structure. Similar to prismatic structure except that the tops of the blocks are rounded.

Complex Soil. (*see* Soil Complex)

Compost. Organic residues or a mixture of organic residues and soil which have been piled, moistened, and allowed to undergo biological decomposition. Mineral fertilisers are sometimes added. Often called *artificial* or *synthetic manure* when produced primarily from plant residues.

Concentrated Flow. An accumulation of a rather large amount of water such as in a gully. Concentrated flow may result in serious erosion.

Concretion. Hardened, local concentrations of certain chemical compounds, such as calcium carbonate or iron oxides, in the form of indurated grains or nodules of various sizes, shapes, and colors.

Conductivity, Hydraulic. (*see* Hydraulic Conductivity)

Consistence. (1) Resistance to deformation of material. (2) The degree of cohesion or adhesion of the soil mass or its resistance to deformation or rupture. Separate terms used for describing these properties at three moisture contents follow :

Consistence when dry : loose, slightly hard, hard, very hard, and extremely hard.

Consistence when moist : loose, very friable, friable firm, very firm, and extremely firm.

Consistence when wet (stickiness): nonsticky, slightly sticky, sticky, and very sticky.

Consistence when wet (plasticity): nonplastic, slightly plastic, plastic, very plastic.

Coppice Mounds. Small mounds of soil material stabilized around desert shrubs.

Cradle Knoll. The earth raised and left in a knoll by an uprooted tree.

Creep. Mass movement of soil and soil material slowly down steep slopes primarily by gravity, but facilitated by saturation with water and alternate freezing and thawing.

Critical Reaction. That pH at which a biological process becomes too slow to measure or at which organisms die.

Cross Slope Bench. A bench terrace running along or near the contour and having a steep drop on the downhill side with an almost level space between terraces.

Crotovina. A former animal burrow in one soil horizon, which has been filled with material from another horizon (also spelled "Krotovina").

Croute Calcaire. Hardened caliche, often found in thick masses or beds overlain by only a few inches of earth. (*see* Caliche)

Crushing Strength. Force required to crush a body of dry soil or dry aggregate.

Crust. A hard or brittle layer formed on the surface of many soils when dry.

Crystal A homogeneous substance bounded by plane surfaces having definite angles with each other and having a regular geometrical form with a definite chemical composition. (*see* Mineral, Soil).

Crystal Lattice. (*see* Lattice Structure).

Crystalline Rock. A rock composed of closely fitting mineral crystals that have formed in the rock substance. Such a rock is in contrast to one made up of cemented grains of sand, volcanic glass, or other material.

Cultivation. A mechanical stirring of the soil in place, as in seedbed preparation or weed control.

Cyclic Salt. Salt brought into the soil by winds off the sea or inland salt lakes.

D

Darcy's Equation. Mathematical formulation of Darcy's Law.

Darcy's Law. (1) Historical: the volume of water passing downward through a sand filter bed in unit time is proportional to the area of the bed and to the difference in hydraulic head, and is inversely propor-

tional to the thickness of the bed. (2) Generalization for three dimensions: the rate of viscous flow of water in isotropic porous media is proportional to, and in the direction of, the hydraulic gradient. (3) Generalization for other fluids: the rate of viscous flow of homogeneous fluids through isotropic porous media is proportional to, and in the direction of, the driving force.

Dark-Gray Gleysolic Soils. A Canadian term referring to an intrazonal group of imperfectly to poorly drained soils having dark gray A horizons, moderately high in organic matter. These soils lie over mottled gray or brownish gleyed mineral horizons; they have a low degree of textural differentiation and are developed under swamp forest.

Decalcification. Removal of calcium carbonate or calcium ions from the soil by leaching.

Decomposition. (*see* Biological Mineralization).

Deflation. Removal of fine soil particles from the soil by wind erosion.

Deflocculate. To separate the individual parts of compound particles by chemical means; more specifically, to disperse particles of colloidal dimensions from a flocculated condition.

Denitrification. The biological reduction of nitrate or the converting of nitrate to gaseous nitrogen (molecular nitrogen or the oxides of nitrogen). The process results in the escape of nitrogen into the air and hence is undesirable in agriculture.

Deposit. Material left in a new position by some natural transporting agent, such as water, wind, ice, or gravity.

Depression Podzol. --Also referred to as Slough, Bluff, or Meadow Podzol. Poorly drained depressional soils of the grassland and park land regions of Canada with bleached A_2 horizons and finer-textured B horizons.

Desert Crust. A hard layer, containing calcium carbonate, gypsum, or other binding materials, which is exposed at the surface in desert regions.

Diatoms. Algae having a siliceous cell wall which persists as a skeleton after death. Any of the microscopic unicellular or colonial algae constituting the class *Bacillariae*. They occur abundantly in fresh and salt waters and are widely distributed in soils.

Diatomaceous Earth. A geological deposit derived chiefly from the remains of diatoms.

Direct Counts. Any of several methods of estimating the total number of microorganisms in a given weight of soil by direct microscopic examination.

Disintegration. (*see* Physical Weathering)

Disperse. To break up compound particles.

Dispersion Medium. Fluid in which particles are dispersed.

D Layer. (*see* Soil Horizon)

Diversion Dam. A structure for deflecting water from one stream to another.

Dominant Trees. Larger-than-average trees in a stand with crowns extending above the general level.

Drag. The retarding force to flowing water or wind over the surface of the ground.

Drain. (verb) (1) To provide outlet channels so that excess water can be removed by surface flow or by downward internal flow through the soil. (2) To lose water by percolation.

Drain Tile. A concrete or pottery pipe for water outlets from soil.

Drainage Terrace. Constructed channel for conducting surplus surface water from land with minimum erosion

Dry Aggregate. A soil aggregate not broken down by dry sieving.

Dryland Farming. The practice of crop production, without irrigation, where rainfall is deficient.

Dust Mulch. An induced loose, fine granular, or powdery condition to the surface soil. (*see* Mulch)

Dynamometer. An instrument for measuring draft of tillage implements and for measuring resistance of soil to penetration by tillage implements.

E

Ecology. The science that deals with the study of the interrelationships of organisms in and to their environment.

Ectodynamorphic. Soils whose properties are influenced mainly by factors other than parent material. (*see* Endodynamorphic)

Edaphic. A term pertaining to the influence or relationship of soil or other similar media to plant growth in contrast to atmospheric influences

Edaphology. The scientific study of the relationships between soils and living things, including man's use of the land.

Electrokinetic or Zeta Potential (1) The difference in potential between the immovable liquid layer attached to the surface of the solid phase and the movable liquid layer in the body of the liquid. (2) The work done in bringing a unit charge from infinity to a reference point in the liquid layer attached to the surface of the solid phase in a colloidal system.

Film Water. Tightly bound water adsorbed on the surface of particles in in unsaturated soil.

Fine sand. (1) A soil separate. (*see* Soil Separates) (2) A soil texture. (*see* Soil Texture)

Fine Texture. (1) Predominating in fine fractions, as fine clay. (2) Includes all clay loams and clays, *i.e.*, clay loam, sandy clay loam, silty clay loam, sandy clay, silty clay, and clay textural classes. Sometimes subdivided into clayey and moderately fine textures.

Firm. A consistence term used in describing moist soil which crushes under moderate pressure between thumb and forefinger, but with a resistance distinctly noticeable. (*see* Consistence)

First Bottom. The normal flood plain of a stream.

Fixed Phosphorus. (1) That phosphorus which has changed to less soluble forms as a result of reaction with the soil; moderately available phosphorus. (2) Applied phosphorus; phosphorus not taken up by plants during the first cropping year. (3) Soluble phosphorus; phosphorus attached to the solid phase of soil in forms highly unavailable to crops. (4) Unavailable phosphorus; phosphorus in other than readily or moderately available forms.

Flaggy (*see* Coarse Fragments)

Flagstone. A relatively thin fragment 6 to 15 inches long, of sandstone, limestone, slate, shale, or (rarely) schist. (*see* Coarse Fragments)

Flood Plain. Land bordering a stream, built of sediments from the stream and subject to flooding in times of high water unless protected artificially.

Flow Velocity (Water in soil). A vector point function used for indicating the rate and direction of movement of water through soil. It is an effective or macroscopic velocity and may not be equal to the particle velocity of the water at any point. Flow velocity is defined as the volume of water transferred per unit of time and per unit of are a normal to the direction of net flow.

Forest Floor. (1) All dead vegetable matter on the mineral soil surface. Includes litter and unincorporated humus. (2) All organic matter, inclusive of litter, on the mineral soil surface of a forest.

Fluvio-Glacial. (*see* Glacio-Fluvial Deposits)

Forest Soils. (1) Any soil developed under trees. (Soils found under temperate forest (European usage).

Fragipan. A natural subsurface horizon with high-bulk density relative to the solum above, seemingly cemented when dry, but when moist showing moderate to weak brittleness. The layer is very low in organic

matter, mottled, slowly or very slowly permeable to water, and usually shows occasional or frequent bleached cracks forming polygons. It may be found in profiles of either cultivated or virgin soils but not in calcareous material.

Friability. The ease of crumbling of soils. (Coherence would determine crushing strength).

Frost, Concrete. That type of frost in the soil which is so filled with ice that it is virtually a solid block.

Frost, Honeycomb. Frost in the soil of a crystalline nature, giving it a loose structure and permitting the ready entrance of water.

Fulvic Acid. A term of varied usage but usually referring to the mixture of organic substances remaining in solution upon acidification of a dilute alkali extract of soil.

G

Genetic. Resulting from soil formation processes, such as a genetic soil profile or a genetic horizon.

Geological Erosion. (*see* Natural Erosion)

Gilgai. Microrelief of clays that have high coefficients of expansion and contraction with changes in moisture; usually a succession of microbasins, and microknolls in nearly level areas or of microvalleys and microridges that run with the slope (*see* Microrelief)

Glacial Drift. A general term for the rock debris that has been transported by glaciers and deposited, either directly from the ice or from the meltwater, with the melting of the glacier. It may be heterogeneous or assorted.

Glacia Soil. (Obsolete). Soil formed from glacial drift.

Glacial Till. (*see* Till)

Glacio-Fluvial Deposits. Material moved by glaciers and subsequently sorted and deposited by streams flowing from the melting ice. These deposits are stratified and may be in the form of outwash plains, deltas, kames, eskers, and kame terraces. (*see* Glacial Drift; Till)

Gleization. The soil formation processes leading to the development of a gley soil. (*see* Humic-Gley Soils ; Dark-Gray Gleysolic Soils)

Glykophytes. Nonhalophytic plants or plants that do not grow well when the osmotic pressure of a salty soil solution rises above two atmospheres.

Grain Density. Same as *particle density*.

Gravelly. A coarse fragment class used in soil textural class names. (*see* Coarse Fragments)

Gravitational Water. Water which moves into, through, or out of the soil under the influence of gravity.

Green Manure. A crop grown for the purpose of being turned under while green, or soon after maturity, for improving the soil.

Gully. A large intermittent water course with steep sides; an obstacle to agricultural machinery.

Gully Erosion. Erosion that results in gullies.

H

Halopyhtic. Able to grow in salty soil.

Hardpan. An indurated or hardened soil horizon caused by cementation of soil particles wiıh organic matter or with materials such as silica, sesquioxides, or calcium carbonate. (*see* Caliche) Hardness or rigidity of horizon does not appreciably change with changes in the water content; pieces of the hard layer do not slake in water.

Heavy Soil. (*Obsolete in scientific use*). (*see* Fine Texture) A soil which has a high drawbar pull; a soil difficult to cultivate.

Heterotrophic. Capable of deriving energy for life processes only from the dissimilation of organic carbon compounds and incapable of using carbon dioxide as the sole carbon source for cell synthesis. Contrast with *autotrophic.*

Horizon. (*see* Soil Horizon)

Hue. One of the three variables of color. The dominant spectral color. The hue changes with the dominant wave length of the light. (*see* Munsell Notation; Chroma; Value)

Humic Acid. A term of varied usage but usually referring to a mixture of indefinite composition of dark-colored organic substances precipitated upon acidification of a dilute alkali extract of soil. Used by some workers to designate only the alcohol-insoluble portion of this precipitate. In chemistry, may represent a preparation obtained by the treatment of sugars with mineral acids.

Humic-Gley Soils. Includes Wiesenboden and those soils, formerly grouped with Half-Bog soils, that have a thin muck or peat A_0 horizon and an A_1 horizon. Developed in wet meadows and forested swamps.

Humification. Processes of organic decomposition leading to the formation of humus.

Humin. Has had varied usage in reference to soil organic matter but usually is applied to that part of the organic matter not dissolved upon extraction of soil with dilute alkali.

Humus (*see* Soil Organic Matter)

Hydraulic Conductivity. The ratio of the flow velocity to the driving force for the viscous flow under saturated conditions of a specified liquid in a porous medium.

Hydraulic Gradient (Water in soil). A vector (macroscopic) point function which is equal to the decrease in the hydraulic head per unit distance through the soil in the direction of the greatest rate of decrease.

Hydraulic Head (Water in soil). The elevation with respect to a standard datum at which water stands in a riser or manometer connected to the point in question in the soil. This will include gravitational head, pressure head, and velocity head, if the terminal opening of the sensing element is pointed upstream.

Hydrogenic Soils. Soil developed under the influence of water standing within the profile for considerable periods, mainly in cold, humid regions.

Hydrologic Cycle. Disposition of rainfall from the time it is precipitated until it re-enters the air masses by re-evaporation to serve again as a source of precipitation.

Hydromorphic Soils. Soil developed in the presence of excess water.

Hygroscopic Water. Water adsorbed to the surface of soil particles when in equilibrium with an atmosphere of 98 per cent relative humidity.

I

Illuvial Horizon. Horizon that has received material in solution or suspension from some other part of the soil.

Illuviation. The process of deposition of soil material removed from one horizon to another horizon of the soil; usually from an upper horizon to a lower horizon in the profile.

Immature Soil. Lacking a well-developed profile.

Immobilization. The conversion of an element from inorganic to organic combination in microbial or plant tissues. This has the effect of rendering unavailable (and usually not readily soluble) an element that previously was directly available to plants.

Impeded Drainage. Condition in which downward movement of gravitational water is hindered.

Impervious. Resistant to penetration by fluids or roots.

Indicator Plants. Plants characteristic of specific soil or site conditions.

Infiltration. The downward entry of water into soil.

Infiltration Rate. The maximum rate at which a soil, in a given condition at a given time, can absorb water. Also, the maximum rate at which a soil will absorb water impounded on the surface at a shallow depth when adequate precautions are taken regarding border or fringe effects. Defined as the volume of water passing into the soil per unit of area per unit of time.

Infiltration Velocity. The volume of water moving downward into the soil surface per unit of area per unit of time. The local instantaneous volume is the limit approached as the area and time interval are made small. The maximum infiltration velocity is the infiltration rate.

Infilterometer. A device for measuring the rate of entry of a fluid into a porous body, *e.g.*, water into soil.

Intergrade. Soils which possess moderately well-developed distinguishing characteristics of two or more genetically related great soil groups.

Ion. Acids, bases, and salts (electrolytes) when dissolved in certain solvents are more or less dissociated into electrically charged units, called *ions*. Some electrolytes dissociate into ions when fused. Positive ions are atoms or a group of atoms which have lost valence electrons; negative ions are those to which additional electrons have been added. Positively charged ions are called *cations*; negatively charged ions are called *anions*.

Ion Activity. The effective concentration of an ion in a solution or soil-water system as determined from the electromotive force of a cell composed of a reference electrode whose potential varies with the activity of the ion under investigation.

Irrigation. Artificial application of water to the soil for supplying water to crops.

Irrigation Efficiency. The ratio of the water consumed by crops of an irrigated farm or project to the water diverted from a river or other natural source into the farm or project canals.

Irrigation Methods :

Border-strip. Water applied at the upper end of a strip with earth borders to confine the water to the strip.

Check Basin. Water applied rapidly to relativly level plots surrounded by levees. The basin is a small check.

Corrugation. Water applied to small, closely packed furrows, frequently in grain and forage crops, to confine the flow of irrigation water to one direction.

Flooding. Water released from field ditches and allowed to flood over the land.

Furrow. Water applied in small ditches made by cultivation implements for tree and row crops.

Sprinkler. Water sprayed over the soil surface through nozzles from a pressure system.

Subirrigation. Water applied in open ditches or tile lines until the water table is raised sufficiently to wet the root zone of the soil.

Wild flooding. Irrigation water released at high points in the field without controlled distribution.

Isodyne. Points of equal dynamometer pull of cultivating implement ; such points connected on a graph to form lines over a map of a cultivated field.

K

Kame An irregular ridge or hill of stratified glacial drift.

L

Lacustrine. Term referring to deposits formed on the bottom of lakes.

Lacustrine Soil (*Obsolete*). Soil formed from lacustrine deposits.

Lagg. The depressed margin of a raised bog.

Land Classification. The classification of units of land for the purpose of showing their relative suitabilities for some specific use.

Land Type. (*see* Soil Association)

Land, Wild. Uncultivated land ; it may or may not be maintained by the owner for its protective vegetative cover, wood, forage production, recreation, or wildlife.

Landscape. All the features that distinguish one part of the earth's surface from another part.

Landslide. (1) Rapid movement downslope of a mass of soil, rock, and debris. (2) Mass of material that has slipped downhill.

Lattice Energy. The energy required to separate the ions of a crystal to an infinite distance from each other.

Lattice Structure. Orderly arrangement of atoms in crystaline material.

Leached Saline Soils. (1) Soils which have had the soluble salts removed by leaching. (2) Soils which have been saline and still possess the major physical characteristics of saline soils but from which the soluble salts have been leached, generally as a result of reclamation.

Lento Capillary Point (*Obsolete*). The amount of water in a soil when the capillary flow is barely adequate to meet the needs of plant growth.

Light Soils (*Obsolete in scientific use*). (*see* Coarse Texture) A soil which has a low drawbar pull ; a soil easy to cultivate.

Lime. Most agricultural lime is calcium carbonate or a mixture of calcium and magnesium carbonate. Chemically speaking, lime is CaO.

Air-slaked lime. A product composed of varying proportions of the oxide, hydroxide, and carbonate of calcium, or of calcium and magnesium, and derived from the exposure of quicklime to the weather.

Agricultural liming material. A material whose calcium and magnesium content is capable of neutralizing soil acidity.

Dolomite. A material composed chiefly of carbonates of calcium and magnesium.

Ground limestone. The product obtained by grinding either calcitic or dolomitic limestone so that all the material will pass through a 10-mesh sieve and at least 50 per cent will pass through a 100-mesh sieve.

Ground shell marl. The product obtained by grinding natural deposits of shell marl so that at least 75 per cent passes a 100-mesh sieve.

Ground shells. The product obtained by grinding the shells of mollusks so that not less than 50 per cent passes through a 100-mesh sieve. The product also carries the name of the mollusk from which the product is made, such as oyster shell lime.

Gypsum, land plaster, or crude calcium sulphate. A product consisting chiefly of calcium sulphate. It does not neutralize soil acidity.

High-calcic products. Materials of which 90 per cent or more of the total calcium and magnesium oxide content consists of calcium oxide.

High-magnesic products. Materials in which more than 10 per cent of the total calcium and magnesium oxide consists of magnesium oxide.

Hydrated or air-slaked lime. A dry product consisting chiefly of the hydroxide of calcium and the oxide and hydroxide of magnesium.

Magnesia (magnesium oxide). A product consisting chiefly of the oxide of magnesium. Its grade is stipulated, for example, Magnesia—75 per cent MgO.

Pulverized limestone (fine-ground limestone). The product obtained by grinding either calcitic or dolomitic limestone so that all the materials will pass through a 20-mesh sieve and at least 75 per cent will pass through a 100-mesh sieve.

Quicklime, Burned lime, Caustic lime, Lump lime, Unslaked lime. Calcined materials, the major part of which is calcium oxide, in natural association with a smaller amount of magnesium oxide, and which is capable of slaking with water.

Waste lime, By-product lime. Any industrial waste or by-product containing calcium or calcium and magnesium in forms that will neutralize soil acidity. It may be designated by prefixing the name of the industry or process by which it is produced, *i.e., gashouse lime, tanners' lime, acetylene lime-waste, lime-kiln ashes*, or *calcium silicate*.

Lime Concrete. An aggregate cemented by precipitation of $CaCO_3$.

Lime Pan. A hardened layer cemented by calcium carbonate.

Lime Requirement. The number of pounds of limestone or other specified liming material required to raise the pH of one acre (six inches or 2,000,000 pounds) of an acid soil to any desired pH value under field conditions.

Liquid Limit Minimum moisture weight percentage at which a small sample of soil material will barely flow under a standard treatment. Sometimes called "upper plastic limit." (*see* Plastic Limit; Plasticity Index)

Lithosequence. A sequence of soils whose properties are functionally related to differences in the parent rock as a soil-formation factor.

Lithosols. An azonal group of soils having an incomplete solum or no clearly expressed soil morphology and consisting of a freshly and imperfectly weathered mass of hard rock or hard rock fragments.

Loamy. A broad grouping of texture classes; includes all sandy loams, clay loams, loam, silt, and silt-loam textures. Sometimes subdivided into moderately coarse-textured, medium-textured, and moderately fine-textured groups.

Loess. A fine-grained aeolian deposit dominantly of silt-sized particles.

Loose. (*see* Consistence).

M

Macroscopic Velocity. (*see* Flow Velocity).

Made-Land. Areas filled with earth, trash, or both.

Manure. (1) The excreta of animals, with or without the admixture of bedding or litter, and of varying stages of decomposition. Also referred to as barnyard, or stable, manure. (The usual meaning of the term in the United States). (2) Any material which fertilises land; a fertiliser of either organic or inorganic origin. (Seldom used in this sense in the United States but frequently so used elsewhere.)

Marl. Earthy deposit of $CaCO_3$.

Marsh. Periodically wet or continually flooded areas with surface not deeply submerged. Covered dominantly with sedges, cattails, rushes, or other hydrophytic plants. Subclasses include fresh-and-salt-water marshes.

Maximum Water-Holding Capacity. The average moisture content of a disturbed sample of soil, one cm. high, which is at equilibrium with a water table at its lower surface.

Meadow Podzol. (*see* Depression Podzol).

Meander-Land. Unsurveyed land, usually between a lake shore or stream border, at the time of a cadastral survey, and the present lower shore or border.

Medium-Textured. Intermediate between fine-textured and coarse-textured soils. Includes very fine sandy loams, loam, silt loam, and silt textural classes.

Mellow. A very soft and very friable, porous soil without tendency to become hard.

Mesophilic Bacteria. Bacteria whose optimum temperatures for growth fall in an intermediate range of approximately 20° to 40°C.

Metamorphic Rocks. Rocks derived from pre-existing rocks by mineralogical, chemical, and structural alterations due to geological processes originating within the earth. Igneous and sedimentary rocks may be changed to metamorphic rock or one metamorphic rock may be changed into another type of metamorphic rock.

Microclimate. (1) A modification of the general climate produced by the local environment. (2) The sequence of atmospheric changes within a very small region.

Microfauna. The part of an animal population comprised of individuals so small that they cannot be clearly distinguished without the use of a microscope. Usually applied to protozoa, nematodes, etc.

Microflora. The part of a plant population comprised of individuals so small that they cannot be distinguished without the use of a microscope. Usually applied to algae, fungi, bacteria, etc.

Microrelief. Small-scale differences in relief, including mounds, swales, or pits that are a few feet across and have differences in elevation up to about six feet. (*see* Coppice Mounds; Cradle Knoll; Gilgai).

Milliequivalent. A thousandth of an equivalent weight, or one milligram of hydrogen or any other ion that will combine with or displace it.

Mine-Dumps. Areas of waste rock, with little or no segregation, that come from ore and coal mines, quarries, and smelters. (*see* Miscellaneous Land Type).

Mine-Wash. Accumulations of sandy, silty, or clayey material recently eroded in mining operations; may clog streams and channels and damage land on which it is deposited.

Mineral, Soil. A natural inorganic compound usually having definite physical properties, crystalline structure, and chemical composition (within the limits of isomorphism).

Mineralization. The conversion of an element that is immobilized in some organic combination to available form as a result of microbial decomposition.

Mineralogical Analysis. Estimation of the kinds or amounts of minerals in soil or rock.

Mineral Soil. A soil whose properties are dominated by the mineral matter; usually containing less than 20 per cent organic matter, or with only a thin surface organic layer (less than 30 cm. thick).

Miscellaneous Land Type. A mapping unit for areas of land that have little or no natural soil, are inaccessible for orderly examination, or in which for some other reason the soil cannot be classified (*see* Badlands; Made-Land; Meander-Land; Mine-Wash, Slickens; Stony-Land; Swamp; Tidal Flats; Urban-Land, Volcanic-Ash-Land; Wasteland).

Moderately Coarse Textured. Includes all sandy loams except the very fine sandy loam textural class. (*see* Coarse Texture).

Moderately Fine Textured. Includes all clay loams, *i.e.*, clay loam, sandy clay loam, and silty clay loam textural classes. (*see* Fine Textured)

Moisture Equivalent. Percentage of water retained in a soil sample one cm. thick after it has been saturated and subjected to a centrifugal force 1,000 times gravity for 30 minutes.

Moisture Tension. The equivalent negative gauge pressure, or suction, in the soil moisture. Soil moisture tension is equal to the equivalent negative gauge pressure to which water must be subjected in order to be in hydraulic equilibrium, through a porous permeable wall or membrane, with the water in the soil.

Moisture Weight Percentage. Moisture content expressed as a percentage of oven-dry (105° to 110°C.) weight of soil. Same as *dry weight percentage.*

Moisture Volume Percentage or Water Ratio. The percentage of the soil bulk volume that is occupied by moisture. Numerically it is equal to depth percentage. The ratio of the volume of water in a soil is equal to the total bulk volume of the soil system.

Mottled Zone. Layer that is marked with spots or blotches of different colors or shades of color. The pattern of mottling and the size, abundance, and color contrast of the mottles may vary considerably and should be specified in soil description.

Mottling. Patch of different colors rather than a mass of one color.

Mountain Soils. (*Obsolete*). General term, usually referring to skeletal soils formed mainly by physical weathering in cool mountain regions.

Mulch. A loose covering on the surface of the soil. Usually consists of organic residues but may be loose soil produced by cultivation or other inorganic materials.

Mulch Farming. A system of farming in which the organic residues are not ploughed into the ground but are left on the surface.

Munsell Notation. A color designation system that specifies the relative degrees of the three simple variables of color: hue, value, and chroma. For example: 10YR 6/4 is a color of soil with a hue=10YR, value=6, and chroma = 4. These notations can be translated into several different systems of color names. (*see* Hue; Value; Chroma).

Mycorrhiza. The morphological association, usually symbiotic. of fungi with the roots of seed plants. The association is referred to as *ectotrophic* in those cases in which the fungi hyphae occur on the root surface and penetrate only the intercellular spaces, and as *endotrophic* when the hyphae occur mainly within the cells of the host plant.

N

Natural Erosion. Erosion of the natural landscape undisturbed by man or domestic animals.

Neutral Soil. Soil in which the upper part is neither acid nor alkaline. (*see* Reaction, Soil; Acid Soil; pH, Soil).

Nitrate Reduction. The biological reduction of nitrates to the nitrite form.

Nitrification. The biological oxidation of ammonium salts to nitrites and the further oxidation of nitrites to nitrates.

Nitrogen Assimilation. The incorporation of nitrogen compounds into cell substances by living organisms.

Nitrogen Cycle. The sequences of transformation undergone by nitrogen wherein it is used by one organism, later liberated upon the death and decomposition of the organism, and is converted by biological means to its original state of oxidation to be reused by another organism.

Nitrogen Fertilisers (Inorganic) :

Ammoniated superphosphate (*see* Phosphorus fertilisers).

Ammonium nitrate. The ammonium salt of nitric acid. It contains not less than 33 per cent nitrogen, one-half of which is in the ammonium form and one-half in the nitrate form.

Ammonium sulphate nitrate. A double salt of ammonium sulphate and ammonium nitrate in equal molecular proportions. It contains not less than 26 per cent nitrogen, one-fourth of which is in the nitrate form and three-fourth in the ammonium form.

Calcium nitrate. The calcium salt of nitric acid. It contains not less than 15 per cent nitrate nitrogen.

Nitrate of potash (potassium nitrate). The potassium salt of nitric acid. It contains not less than 12 per cent nitrogen and 44 per cent potash (K_2O).

Nitrate of soda (sodium nitrate). The sodium salt of nitric acid. It contains not less than 16 per cent nitrate nitrogen and 26 per cent sodium.

Sulphate of ammonia (ammonium sulphate). The ammonium salt of sulphuric acid. It contains not less than 20.5 per cent nitrogen.

Nitrogen Fertilisers (Natural Organic) :

Acidulated fish tankage, acidulated fish scrap. The rendered product derived from fish and treated with sulphuric acid.

Activated sewage products. Made from sewage that has been aerated and inoculated with microorganisms. The resulting flocculated organic matter is filtered, dried, ground, screened, bagged, and sold as a fertiliser.

Bat guano. Partially decomposed bat manure of variable composition.

Dried blood. The collected blood of slaughtered animals that has been dried and ground. It contains not less than 12 per cent nitrogen in several organic forms.

Dried, pulverized, or shredded manures. These are what the names indicate, and not mixtures of manures and other materials.

Fish tankage, fish scrap, dry ground fish, fish meal. The dried, ground products derived from rendered or unrendered fish.

Garbage tankage. The rendered, dried, and ground product derived from waste household food materials.

Hoof and horn meal. Processed, dried, and ground hoofs and horns.

Peat. Partly decayed organic matter of natural occurrence.

Process tankage. Products made under steam pressure from crude, inert nitrogenous materials, with or without the use of acids, for the purpose of increasing the activity of the nitrogen.

Sheep manure-wool waste. The by-product from wool-carding establishments, consisting chiefly of sheep manure, trash from dirty wool, and wool waste.

Tankage. The rendered, dried, and ground by-products, largely consisting of the meat and bones of slaughtered animals.

Nitrogen Fertilisers (Synthetic Organic) :

Cyanamid. A commercial product consisting principally of calcium cyanamid ($CaCN_2$) and carbon. It contains not less than 20 per cent nitrogen and 54 per cent calcium oxide.

Urea. The commercial synthetic acid amide of carbonic acid. It contains not less than 42 per cent nitrogen.

Urea-formaldehyde fertiliser materials. Reaction products of urea and formaldehyde containing at least 35 per cent nitrogen, largely in an insoluble but slowly available form.

Nitrogen Fixation. The conversion of elemental nitrogen to organic combinations, or to forms readily utilizable in biological processes, by nitrogen-fixing microorganisms. When brought about by bacteria in the root nodules of leguminous plants, it is spoken of as *symbiotic ;* if by free-living microorganisms acting independently, it is referred to as *nonsymbiotic fixation.*

Nodule Bacteria. (*see Rhizobia*).

Nonsymbiotic. Independent or free-living organisms ; commonly refers to organisms capable of fixing nitrogen apart from leguminous plants.

Normal Erosion. The gradual erosion of land used by man which does not greatly exceed natural erosion.

O

Organic Phosphorus. Phosphorus present as a constituent of an organic compound or a group of organic compounds, *e.g.*, glycerophosphoric acid, inosital phosphoric acid, cytidylic acid.

Ortstein. The B horizon of Podzols that are cemented by the accumulated sesquioxides and/or organic matter.

Oven-Dry Soil. A soil dried at 105° to 110°C. until it is in moisture equilibrium at that temperature.

P

Pans. Horizons or layers, in soils, that are strongly compacted, indurated, or very high in clay content. (*see* Claypan ; Caliche).

Pan, Genetic. A natural subsurface soil layer development of low or very low permeability and with particle size analysis and chemical properties of the soil differing from that immediately above or below the pan. (*see* Claypan, Fragipan, and Hardpan, all of which are genetic pans).

Pan, Pressure or Induced. An artificial subsurface soil horizon or layer having a higher bulk density and lower total porosity than the soil material directly above and below, but similar in particle size analysis and chemical properties. The pressure pan is usually found at the lower depth of normal cultivation and is variously called a *plowpan, plowsole*, or a *tillage* or *traffic pan* or *sole.*

Partial Sterilization. The incomplete elimination of microorganisms in soil or other substrates usually by treatment with heat or chemicals. The process is selective in action, certain organisms or groups of organisms being destroyed to a greater extent than others or, in some cases, being completely eliminated.

Particle Density. The average density of the soil particles not including fluid space. Particle density is usually expressed in grams per cubic centimeter and is sometimes referred to as "real density" or "grain density."

Particle Size. The effective diameter of a particle measured by sedimentation, sieving, or micrometric methods.

Parts Per Million (ppm). Weight units per million weight units of soil, oven-dry basis. "Parts per million" expresses grams per million grams soil or pounds per million pounds soil ; or, in the case of soil solution or other solution, it expresses weight units per million weight units of solution. "Parts per million" should be given preference to "pounds per acre" in technical writing.

Peneplain. A land surface which has become nearly level, as the result of erosion.

Penetrability. The work required to push a probe a unit distance into the soil.

Percolation (soil water). A qualitative term applying to the downward movement of water through soil. Especially, the downward flow of water in saturated or nearly saturated soil at hydraulic gradients of the order of one or less.

Permafrost. (1) Permanently frozen material underlying the solum. (2) Perennially frozen soil horizon.

Permafrost Table. The upper boundary of the permafrost, coincident with the lower limits of seasonal thaws.

Permeability. (1) (Soil) *Permeability*, as used in describing soils, refers to the readiness with which air, water, or plant roots penetrate into or pass through its pores. The portion of the soil being discussed should be designated, *e.g.*, "the permeability of the A horizon." (2) (Qualitative) The quality or state of a porous medium, relating to the readiness with which it conducts or transmits fluids. (3) (Quantitative) The specific property designating the rate or readiness with which a porous medium transmits fluids under standard conditions.

pH, Hydrolytic. The arithmetical difference between the pH value of a soil as measured on the soil paste and the value obtained on a 1:10 suspension.

pH, Isohydric. The pH value of a soil identical with that of a buffer solution which remains unchanged when mixed with the soil.

pH, Soil. The negative logarithm of the hydrogen-ion activity of a soil. The degree of acidity (or alkalinity) of a soil as determined by means of a glass—quinhydrone—or other suitable electrode or indicator at a specified moisture content or soil-to-water ratio, and expressed in terms of the pH scale, from 0 to 14.

Phosphorus Fertilisers.

Acidulated bone. Ground bone or bone meal that has been treated with sulphuric acid.

Ammoniated superphosphate. A product obtained when superphosphate is treated with ammonia or with solutions which contain ammonia or other compounds of nitrogen.

Ammonium phosphate. A product obtained when phosphoric acid is treated with ammonia ; it consists principally of mono-ammonium phosphate, di-ammonium phosphate, or a mixture of these two salts.

Ammonium phosphate sulphate. A product obtained when a mixture of phosphoric acid and sulphuric acid is treated with ammonia. It consists principally of a mixture of ammonium phosphate and ammonium sulphate.

Available phosphoric acid. The sum of the water-soluble phosphoric acid (monocalcium phosphate) and citrate-soluble phosphoric acid (dicalcium phosphate).

Basic phosphate slag. A by-product of the manufacture of steel from phosphatic iron ores. It contains not less than 12 per cent total phosphoric acid of which at least 80 per cent is available (citrate-soluble). It is ground so that not less than 70 per cent of the material passes through a 100-mesh sieve and 90 per cent passes through a 50-mesh sieve.

Calcium metaphosphate. A vitreous product resulting from the treatment of phosphorus rock with gaseous phosphorus pentoxide (P_2O_5) at high temperatures.

Citrate-soluble (reverted) phosphoric acid. That part of the total phosphoric acid in a fertiliser that is insoluble in water but soluble in a neutral solution of citrate of ammonia. Mostly in the form of dicalcium phosphate, $Ca_2H_2 (PO_4)_2$.

Dicalcium phosphate. A manufactured product consisting chiefly of the dicalcic salt of phosphoric acid, $Ca_2H_2 (PO_4)_2$.

Fused calcium-magnesium phosphate. A vitreous product resulting from the fusion of phosphate rock with magnesium silicate

Fused tricalcium phosphate. A product resulting from the fusion of phosphate rock to produce the alpha form of tricalcium phosphate.

Ground raw bone. Ground animal bones that have not been steamed under pressure.

Ground steamed bone. Ground animal bones that have been steamed under pressure.

Phosphate rock. A natural rock containing one or more calcium phosphate minerals of sufficient purity to permit its use, either directly or after concentration, in the manufacture of commercial phosphorus fertilisers. The phosphorus is mostly in the form of tricalcium phosphate, $Ca_3 (PO_4)_2$.

Phosphoric acid. Designates phosphorus pentoxide (P_2O_5).

Precipitated phosphate. A product consisting mainly of dicalcium phosphate obtained by neutralizing, with calcium hydroxide, the acid solution of either phosphate rock or processed bone.

Soft phosphate with colloidal clay. A very finely divided low-analysis by-product from mining Florida rock phosphate by an hydraulic process in which the colloidal materials settle in artificial ponds.

Superphosphate. A product obtained when rock phosphate is treated with either sulphuric acid, phosphoric acid, or a mixture of those acids. The guaranteed percentage of available phosphoric acid is stated as a part of the name, such as "20 per cent superphosphate".

Photomap. An aerial mosaic map with physical and cultural features shown as on a planimetric map. The sheets are laid out uniformly on a definite projection as is done with standard topographic or planimetric maps. They are usually reproduced in large quantities by offset lithography or a similar process.

Physical Properties. Soil properties related to or caused by the forces and operations of physics.

Physical Weathering. The breakdown of rock and mineral soil into smaller fragments by physical forces, as by frost action. (*see* Weathering).

Physisorption. Process of attachment of molecules to a surface by other-than-ionic processes. Examples are polar attachment of water molecules to solid-phase surfaces of soil, and of acetic acid molecules to clay (ionic processes may also attach large molecules to clay surfaces, but these are not processes of physisorption). Physisorption is active in attachment of certain organic phosphorus compounds such as nucleic acid to clays, but is not active in the attachment of phosphate ions.

Phytogenic Soils. Soils developed under the dominant influence of the natural vegetation, mainly in temperate regions.

Phytometer. A plant or plants used to measure the physical factors of the habitat in terms of physiological activities.

Phytomorphic Soils. The Canadian term for the well-drained soils of an association which have developed under the dominant influence of the natural vegetation characteristics of a region. The zonal soils of an area.

Plastic. Capable of undergoing deformation without rupture.

Plastic Limit. Minimum moisture weight percentage permitting deformation of a small sample of soil material without rupture. Sometimes called *lower plastic limit*. (*see* Liquid Limit ; Plasticity Index).

Plasticity Index or Plasticity Number. The numerical difference between the liquid and the plastic limits.

Plasticity Range. Range of moisture weight percentage within which a small sample of soil materials exhibits plastic properties.

Plate Count. A method for estimating the number of microorganisms in a given weight of soil which will form colonies on semisolid nutrient media.

Platy. Soil aggregates predominantly developed along the horizontal axes, *i.e.*, laminated.

Pocasin. A local term for a swamp, usually containing more or less peat; characteristic of Southeastern United States.

Pore Space. Total space not occupied by solid soil particles.

Porosity. The fraction of the total soil volume not occupied by solid particles.

Pitchy. Dense and hard when dry, breaking with smooth somewhat lustrous fracture into sharp-angled (conchoidal) fragments. Wet pitchy peat is very plastic and if squeezed in the hand oozes out between the fingers.

Potassium Fertilisers.

Double sulphate of potash-magnesia (langbeinite). The double sulphate of potash magnesium ($K_2SO_4.2MgSO_4$) is a commercial product containing 22 per cent potash (K_2O) and 18 per cent MgO. It is usually sold under the trade name of Sul-Po-Mag.

Kainit. A potash salt containing potassium and sodium chlorides and sometimes sulphate of magnesia, with not less than 12 per cent potash (K_2O).

Mine-run potash salts. Potash salts containing a high percentage of chloride and from 20 to 30 per cent potash (K_2O).

Muriate of potash (commercial potassium chloride). A potash salt containing 48 to 62 per cent potash (K_2O), chiefly in the chloride form.

Potassium metaphosphate. A product composed of phosphoric acid (P_2O_5) and potash (K_2O). Example: Potassium metaphosphate, 55 per cent available phosphoric acid (P_2O_5) and 37 per cent water-soluble potash (K_2O).

Sulphate of potash (commercial potassium sulphate). A potash salt containing not less than 48 per cent potash (K_2O), chiefly as sulphate and not more than 2.5 per cent chlorine.

Wood ashes, leached. Ashes that have been exposed to or digested in water or other liquid solvents, as in the extraction of dyes, so that part of the plant nutrients have been dissolved and removed.

Wood ashes, unleached. Ashes that have had no part of their plant nutrients removed. They contain 4 per cent or more of water-soluble potash (K_2O) and 50 per cent or more CaO.

Potassium Fixation. The process of converting exchangeable or water-soluble potassium to moderately available potassium, a form not easily exchanged from the soil complex, with a cation of a neutral salt solution.

Potassium-Supplying Power of Soils. The capacity of the soil to supply potassium to growing plants from both the exchangeable and the moderately available forms.

Prairie Soils. A zonal group of soils having a dark-colored, granular A_1 horizon six inches or more thick, resting on brown, yellowish-brown, or grayish-brown subsoil frequently mottled, commonly having a blocky structure, and usually higher in silicate clay content than the adjoining horizons. The organic matter in the surface horizon decreases gradually with depth and has a C/N ratio of approximately 11:2. The exchange complex contains less exchangeable H than other cations. They are usually developed under grass vegetation in a humid to semihumid temperate climate.

Pressure Membrane. A membrane, permeable to water and only very slightly permeable to gas when wet, through which water can escape from a soil sample in response to pressure gradients.

Prismatic Soil Structure. Prism-like structure with the vertical axis of the aggregates longer than the horizontal.

Productivity. Soil productivity is the capacity of a soil, in its normal environment, for producing a specified plant or sequence of plants under a specified system of management. In the definition of productivity the specifications are necessary, since no soil can produce all crops with equal success nor can a single system of management produce the same effect on all soils. Productivity emphasizes the capacity of soil to produce crops and should be measured in terms of unit yields.

Productive Soil. A soil in which the chemical, physical, and biological conditions are favourable for the economic production of the crops suited to a particular area.

Psammophytes. Plants usually found on sand.

Pure Culture. The growth of a single species or strain of an organism without contact or association with other living species or strain.

R

Rainfall Interception. Interception of the fall of raindrops by a canopy vegetation or vegetative residue.

Reaction, Soil. The degree of acidity or alkalinity of a soil, usually expressed in terms of pH value. Descriptive terms commonly used are as follows: *extremely acid*, below 4.5; *very strongly acid*, 4.5 to 5.0; *strongly acid*, 5.1 to 5.5; *medium acid*, 5.6 to 6.0; *slightly acid*, 6.1 to 6.5; *neutral*, 6.6 to 7.3; *mildly alkaline*, 7.4 to 7.8; *moderately alkaline*, 7.9 to 8.4; *strongly alkaline*, 8.5 to 9.0; *very strongly alkaline*, 9.1 and higher.

Red Earth. Leached, red, deep, clayey soils of the humid tropics, low in silica.

Regolith. The unconsolidated mantle of weathered rock and soil material on the earth's surface; loose earth materials above solid rock. This is approximately equivalent to the term "soil" as used by many engineers.

Regosols. An azonal group of soils lacking definite genetic horizons and deriving from deep soft mineral deposits, such as loess or glacial drift.

Regur. An intrazonal group of dark calcareous soils high in clay, which is mainly montmorillonitic in character, formed mainly from rocks low in quartz; occurring extensively on the Deccan Plateau of India.

Rendzina Soils. (1) (United States) An intrazonal group of soils with brown or black friable surface horizons underlain by light gray to pale yellow calcareous material; developed from soft, highly calcareous parent material under grass vegetation or mixed grasses and forest in humid and semiarid climates. (2) (Europe) A group of calcareous soils with dark gray to nearly white surface horizons that are usually stony and grade into partially disintegrated limestone at shallow depths. These would be called "Lithosols" in the United States.

Residual Material. Unconsolidated and partly weathered mineral materials accumulated by disintegration of consolidated rock in place.

Residual Shrinkage. The decrease in volume after the proportionality between water loss and volume change ceases.

Residual Soil (*Obsolete*). Soil resting on consolidated rock of the same kind as that from which it was formed. (*see* Residual Material)

Retentivity Profile (Soil). A graph showing retentivity values such as 15-atmosphere percentage or 1/10-atmosphere percentage in relation to depth in field soil.

Reticulate Mottling. A network of streaks of different colors; most commonly found in the deeper profiles of latosolic soils.

Reversion. The interaction of a soluble plant nutrient with the soil which causes a precipitation of the nutrient in a less soluble form. The term is usually restricted to the conversion of monocalcium phosphate to the less soluble dicalcium phosphate.

Rhizobia. The bacteria capable of living in symbiotic relationship with leguminous plants in nodules on the roots, the association usually being capable of fixing nitrogen (from the generic name *Rhizobium*).

Rhizoplane. The external surface of plant roots. The microflora of the rhizoplane is found on the surface of plant roots.

Rhizosphere. The soil region in the immediate vicinity of the plant roots in which the abundance or composition of the microbial population is affected by the presence of the roots. The microflora of the rhizosphere is found in this region.

Rill. A small, intermittent water course with steep sides and no obstacle to agricultural machinery ; usually a few inches in depth.

Rill erosion. Formation of small channels or rills by the uneven removal of surface soil by running water.

River-Wash. Barren alluvial land, usually coarse-textured, exposed along streams at low water and subject to shifting during normal high water. (*see* Miscellaneous Land Type).

Rock-Land. Areas containing frequent rock outcrops and shallow soils. Rock outcrops usually occupy 25 to 90 per cent of the area.

Rolling. Having moderately steep, complex slopes ; intermediate between undulating and hilly.

Rough-Broken-Land Very steep land, ordinarily not stony, broken by numerous intermittent drainage channels but having a vegetative cover. (*see* Miscellaneous Land Type ; Badlands).

Rubble-Land. Areas with 90 per cent or more of the surface covered by stones and boulders.

S

Saline-Alkali Soil. (1) A soil containing sufficient exchangeable sodium to interfere with the growth of most crop plants and containing appreciable quantities of soluble salts. The exchangeable sodium percentage is greater than 15 and the conductivity of the saturation extract is greater than four millimhos per centimeter (at 25°C). The pH of the saturated soil is usually less than 8.5. (2) A saline-alkali soil has a combination of harmful quantities of salts and either a high alkalinity or high exchangeable sodium, or both, so distributed in the profile that the growth of most crop plants is reduced.

Saline Soil. A nonalkali soil containing sufficient soluble salts to impair its productivity. (Formerly any soil containing sufficient soluble salts to interfere with plant growth.)

Salinization. The process of accumulation of salts in soil.

Salt-Affected Soil. Soil that has been adversely modified for growth of most crop plants by the presence or action of soluble salts. The term includes soil having an excess of salts, an excess of exchangeable sodium, or both. (*see* Saline Soil ; Sodic Soil).

Sands. (*see* Soil Separates ; Soil Texture)

Sandy. A term which refers to sand and loamy sand textures.

Sandy Clay. A soil texture class. (*see* Soil Texture).

Sandy Clay Loam. A soil texture class. (*see* Soil Texture).

Sandy Loam. A soil texture class. (*see* Soil Texture)

Saturate. (1) To fill all the voids between soil particles with liquid. (2) To form the most concentrated solution possible under a given set of physical conditions in the presence of an excess of the substance.

Scoria Land. Areas of slaglike clinkers, burned shale, and fine-grained sandstone ; Characteristic of burned-out coal beds. It commonly supports a sparse cover of grasses but is of low value for crops.

Second Bottom. The first terrace above the normal flood plain of a stream.

Sedimentary Rock. A rock composed largely of sediments more or less consolidated ; the chief sedimentary rocks are sandstones, shales, limestones, and conglomerates.

Self-Mulching Soil. (1) A soil that cracks deeply and becomes so granular at the surface when very dry that the granular mulch washes into the cracks when rains begin, the whole soil swelling enough as it becomes moist to force material upward between the former cracks. (2) A soil in which the surface layer becomes so well aggregated that it does not crust and seal under the impact of rain.

Shaly. A coarse-fragment class used in soil texture class names. (*see* Coarse Fragments).

Shear. Force, as of a tillage implement, acting at right angles to the direction of movement.

Sheet Erosion. The gradual uniform removal of the earth's surface by water without the formation of rills or gullies.

Silica-Alumina Ratio (1) The molecular ratio of silica to alumina in a soil, clay, or other alumino-silicate mineral. (2) The quotient obtained when the number of mol-fractions of silica is divided by the number of mol-fractions of alumina, both determined by standard fusion analysis of the soil or some part of it.

Silting. The deposition of water-borne sediments, chiefly silt, in lakes, reservoirs, stream channels, or overflow areas.

Silt Loam. A soil texture class. (*see* Soil Texture)

Silty Clay Loam. A soil texture class. (*see* Soil Texture)

Site. (1) An area, considered according to its ecological factors with reference to capacity to produce vegetation ; the combination of biotic, climatic, and natural biotic conditions to produce a particular climax vegetation.

Slaty. A coarse-fragment class used in soil texture class names (*see* Coarse Fragments).

Slickens. Accumulations of fine textured materials separated in place-mine and ore-mill operations ; may be detrimental to plant growth but are usually confined to specially constructed basins.

Slick Spots. Small areas in a field that are slick when wet, owing to alkali or highly exchangeable sodium.

Slough Podzol. (*see* Depression Podzol).

Sodic Soil. Soil that contains sufficient sodium to interfere with the growth of most crop plants ; soils for which the exchangeable-sodium percentage is 15 or more.

Sodium (Sodic) Claypan. (*see* Alkali Claypan).

Soil. (1) The natural medium for the growth of land plants. (2) A dynamic natural body on the surface of the earth in which plants grow, composed of mineral and organic materials and living forms. (3) The collection of natural bodies occupying parts of the earth's surface that support plants and that have properties due to the integrated effect of climate and living matter acting upon parent material, as conditioned by relief, over periods of time. (4) A three-dimensional body on the surface of the earth that is unlike the adjoining bodies. The area of individual soils ranges from less than one-half an acre to more than 300 acres. The terms, "the soil" and "soil," are collective terms used for all soils and are equivalent to the word *vegetation* used for all plants.

Soil Air. The combination of gases occurring in the gaseous phase in soil.

Soil Alkalinity. The degree or intensity of alkalinity of a soil expressed in terms of the pH scale. (*see* Reaction, Soil).

Soil Association. (1) A group of defined and named taxonomic soil units occurring together in an individual and characteristic pattern over a geographic region, comparable to plant associations in many ways. (2) A mapping unit used on general soil maps, composed of two or more defined taxonomic units geographically associated, but the scale and

purpose of the map does not permit or require the delineation of the individual soils. A soil association is described in terms of the taxonomic units included, their relative proportions, and their pattern of association if one exists in the area. Sometimes called "natural land type." (*see* Soil Complex; Undifferentiated Soil Groups).

Soil Auger. A tool for boring into the soil and withdrawing a small sample for field or laboratory observation; augers are of two general types: those with worm-type bits and those of a hollow-cylinder type with cutting edge at one end.

Soil Characteristic. A feature of a soil that can be seen and/or measured in the field or in the laboratory on soil samples. Examples of soil characteristics include soil slope, stoniness, texture, structure, color, and chemical composition.

Soil Classification. Study of soils and their interrelationships, description of their properties, naming them, and grouping them systematically. The taxonomic units are frequently regrouped for various purposes such as drainage requirements, crop adaptations, highway construction, and forestry purposes.

Soil Complex. A mapping unit used in detailed soil surveys where two or more defined taxonomic units are so intimately associated geographically that they cannot be separated by boundaries at the scale used.

Soil Creep. (*see* Creep).

Soil Extract. The solution separated from a soil suspension or a soil at a particular moisture content by filtration, centrifugation, or displacement.

Soil Formation Factor. The independent variables that define the soil system. Five main groups of soil formation factors are generally recognized by soil scientists, *viz*, parent rock, climate, organisms, topography, and time.

Soil Horizon. A layer of soil or soil material approximately parallel to the land surface and differing from adjacent genetically related layers in properties such as color, structure, texture, consistence, and biological and chemical characteristics.

Soil Improvement. The processes for, or the results of making the soil more productive for growing plants by fertilisation, drainage, addition of organic matter, irrigation, and the like.

Soil Management Groups. Groups of taxonomic soil units with similar adaptations or management requirements for one or more specific purposes, such as adapted crops or crop rotations, drainage practices, fertilisation, forestry, highway engineering, etc.

Soil Map. A map designed to show the distribution of soil types or other soil-mapping units in relation to the prominent physical and cultural features of the earth's surface. The following kinds of soil maps are recognized in the United States:

Soil map (detailed). A soil map on which the boundaries between all soil types that are significant to potential use (generally, field-management system) are shown. The scale of the map depends upon the purpose to be served, the intensity of land use, the pattern of soils, and the scale of other cartographic materials available. Traverses are usually made at one-quarter-mile or more frequent intervals. Commonly a scale of 4 inches = 1 mile (1 : 15,840) is now used for field mapping in the United States.

Soil map (detailed reconnaissance). In a detailed reconnaissance map, some portions satisfy the specifications for detailed soil maps while other portions are reconnaissance soil maps.

Soil map (generalized.) Small-scale maps made to bring out the contrast within large areas by generalization of more detailed maps. They vary from soil association maps of a county, on a scale of 1 inch = 1 mile (1:63,460) to maps of larger regions showing associations dominated by one or more great soil groups.

Soil map (reconnaissance). Made by observation of the area at intervals such that the complete land area is not examined as is the case with detailed surveys. The intervals of traversing vary from about one half mile to several miles. The units shown are soil associations. The maps are usually made for exploratory purposes to outline areas of soil suitable for more intensive development. The scale is usually smaller than for detailed maps.

Soil map (schematic.) Very small-scale maps (1:1,000,000 or smaller) compiled from the scant existing knowledge of new and undeveloped regions by the application of existing information about the relationship of soil properties to the soil-formation factors (climate, living organisms, relief, parent rocks, and time) of the area.

Soil Moisture. Water contained in soil.

Soil Moisture Tension. (*see* Moisture Tension).

Soil Monolith. A vertical section taken out of a soil profile and mounted for display or study.

Soil Morphology. (1) The constitution of the soil body as expressed in the kinds, thickness, and arrangement of the horizons in the profile, and in the texture, structure, consistence, porosity, and color of each horizon. (2) The properties of the soil body or any of its parts.

Soil Organic Matter. The organic fraction of the soil. Includes plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as those organic materials which accompany the soil when put through a two-mm. sieve.

Soil Phase. The subdivision of a soil type having variations in characteristics not significant to the classification of the soil in its natural landscape but significant to the use and management of soil. Examples of the variations recognized by phases of soil types include differences in slope, stoniness, and thickness resulting from accelerated erosion.

Soil Piping or Tunneling. Accelerated erosion which results in subterranean voids and tunnels.

Soil Population. All of the organisms living in the soil; the combined soil fauna and flora.

Soil Pores. Interstices between soil particles (voids).

Soil Porosity. The fraction or percentage of the total volume of a soil material not occupied by soil particles.

Soil Profile. A vertical section of the soil through all of its horizons and extending into the parent material.

Soil Province *(Obsolete)*. Areas similar in mode of origin of the soil parent materials or with similarities of geologic and geographic features.

Soil Quality. An attribute of a soil that cannot be seen or measured directly from the soil alone but which is inferred from soil characteristics and soil behavior under defined conditions. Fertility, productivity, and erodibility are examples of soil qualities.

Soil Reaction. (*see* Reaction, Soil).

Soil Salinity. The amount of soluble salts in a soil, expressed in terms of percentage, parts per million, or other convenient unit.

Soil Separates. Mineral particles, less than two mm. in equivalent diameter, ranging between specified size limits. The names and sizes of separates recognized in the United States are. *very coarse sand* (2.0-1.0 mm.),[1] *coarse sand* (1.0-0.5 mm.), *medium sand* (0.5-0.25 mm.), *fine sand* (0.25-0.10 mm.), *very fine sand* (0.10-0.05 mm.), *silt* (0.05-0.002 mm.), and *clay* (< 0.002 mm.).[2] The separates recognized by the International Society of Soil Science are : I (2.0-0.2 mm.), II (0.2-0.02 mm.), III (0.02-0.002 mm.), IV (< 0.002 mm.).

[1] Prior to 1947 this separate was called *fine gravel, now* "fine gravel" includes particles between 2.0 mm. and about 12.5 mm. in diameter.

[2] Prior to 1937 *clay* included particles less than 0.005 mm. in diameter, and *silt* included those particles from 0.05-0.005 mm.

Soil Series. A group of soils that have soil horizons similar in their differentiating characteristics and arrangement in the soil profile, except for the texture of the surface soil, and are formed from a particular type of parent material. Soil series is an important category in detailed soil classification. Individual series are given proper names from place names near the first recorded occurrence. Thus, names such as *Miami*, *Houston*, *Cecil*, and *Barnes* are names of series that appear on soil maps, and each connotes a unique combination of many soil characteristics.

Soil Solution. The aqueous solution existing in equilibrium with a soil at a particular moisture tension and whose chemical composition is determined, not only by soluble electrolytes and nonelectrolytes, but also by direct dissociation of ions on the surfaces of the soil colloids.

Soil Structure. The arrangement of primary soil particles into compound particles or clusters that are separated from adjoining aggregates and have properties unlike those of an equal mass of unaggregated primary soil particles. The principal forms of soil structure are *platy*, *prismatic*, *columnar* (prisms with rounded tops), *blocky* (angular or subangular) and *granular*. Structureless soils are: (1) *single-grain* (each grain by itself, as in dune sand) or (2) *massive* (the particles adhering together without any regular cleavage, as in many claypans and hardpans.

Soil Survey. The systematic examination, description, classification, and mapping of soils in an area. Soil surveys are classified according to the kind and intensity of fields examinations.

Soil Texture. The relative proportions of the various soil separates in a soil material.

Soil Type. A subgroup or category under the soil series based on the texture of the surface soil. A soil type is a group of soil having horizons similar in differentiating characteristics and arrangement in the soil profile, and developed from a particular type of parent material. The name of a soil type consists of the name of the soil series plus the textural class name of the surface soil. Thus, *Miami silt loam* is the name of a soil type within the Miami series.

Soil Variant. A soil whose properties are believed sufficiently different from other known soils to justify a new series name but whose geographic area is so limited that creation of a new series is not believed to justified.

Solclime. The temperature and moisture conditions of the soil ; the soil climate.

Solodized Soil. A soil that has been subjected to the processes responsible for the development of a Soloth and having at least some of the characteristics of Soloth.

Soluble-Sodium Percentage (SS). The proportion of sodium ions in solution in relation to the total cation concentration, defined as follows :

$$SSP = \frac{\text{Soluble sodium concentration (me./litre)}}{\text{Total cation concentration (me./litre}} \times 100$$

Solum (plural, sola). The upper, most weathered part of the soil profile ; includes A and B horizons.

Splash Erosion. The removal of soil particles from their position by the beating effect of rain drops.

Spoil Bank. Rock-waste banks and dumps from the excavation of ditches.

Sticky Point. The moisture content of well-mixed, kneaded soil material that barely fails to adhere to a polished nickel or stainless steel surface when the shearing speed is five cm. per second. It is a property of plastic soils.

Stokes' Law. (1) An equation relating the settling velocity of a smooth, rigid sphere in a viscous fluid to the diameter of the sphere when subjected to a known force field. (2) Stokes' Law gives the rate of fall of a small sphere in a viscous fluid. When a small sphere falls under the action of gravity through a viscous medium, it ultimately acquires a constant velocity (V) as follows :

$$V = \frac{2gr^2(d_1-d_2)}{9_n}$$

where r is the radius of the sphere, d_1 and d_2 the densities of the sphere and the medium, respectively, and μ the coefficient of viscosity.

Stones. Rock fragments greater than 10 inches in diameter if rounded, and greater than 15 inches along the longer axis if flat. (*see* Coarse Fragments).

Stoniness. The relative proportion of stones present ; used in classification of soils. (*see* Coarse Fragments)

Stony. Soils containing sufficient stones to intefere with or prevent tillage. Stones usually occupy more than 0.01 per cent of the surface.

Stony-Land. Areas containing so many stones that use of machinery is impractical; usually 15 per cent to 90 per cent of the surface is covered with stones. (*see* Stoniness; Rubble-Land; Miscellaneous Land Type).

Stratified. Deposited in layers.

Strip Cropping. Practice of growing different types of crops, such as row and sod, in alternate strips along contours or across the prevailing direction of wind.

Structure Index. A soil property which is measurable and may be evaluated on a numerical scale and is related to soil structure.

Stubble Mulch. The stubble of crops or crop residues left essentially in place on the land as a surface cover before and during the preparation of the seedbed and at least partly during the growing of a succeeding crop.

Subarctic Brown Forest Soils. Similar to Brown Forest except for more shallow sola and temperatures averaging less than 5°C., 18 inches or more below the surface.

Subirrigation. (*see* Irrigation Methods).

Subsoiling. Breaking of compact subsoils, without inverting them, with a special knife-like instrument which is pulled through the soil at depths usually of 12 to 24 inches and at spacings of two to five feet.

Substrate. The substance or material on which an organism grows.

Subsurface Tillage. Tillage with a special sweep-like plough or blade which does not turn the surface cover and incorporate it into the soil.

Sulfofication. (*Obsolete*). The biological oxidation of sulphur and its compounds.

Surface Sealing. The orientation and packing of dispersed soil particles in the immediate surface layer of soil whereby it becomes almost impermeable to water.

Surface Soil. The upper part of the soil ordinarily moved in tillage, or its equivalent in uncultivated soils, about 10 to 20 cm. in thickness.

Swamp. Any area, such as a marsh or bog, where the ground is saturated with water throughout much of the year, but during most of the year the surface of the soil is not deeply submerged.

Symbiosis. The living together in more or less intimate association of two dissimilar organisms. Common examples are lichens (algae and fungi) and leguminous plants living in association with *rhizobia*. However, the latter association may sometimes be parasitic.

T

Tabidum. Horizon of fermentation, including duff and humic layer.

Taluds. Short, steep escarpments formed gradually at the downslope margins of fields by deposition against hedges or stone walls.

Talus, Fragments of rocks and other soil material accumlated by force of gravity at the foot of cliffs or steep slopes.

Texture. (*see* Chapter 2).

Textural Classification. (*see* Chapter 2).

Thermal Analysis. Method of analyzing a soil sample for constituents based on a differential rate of heating between the unknown and standard samples when a uniform source of heat is available.

Thermogenic Soils. Soils in which the dominant soil formation factor has been the high temperature , developed in subtropical and equatorial regions.

Thermophilic Bacteria. Bacteria which are active at high tempratures, usually between 37° and 75°C., with an optimum between about 45° and 55°C.

Thermosequence. A sequence of soils whose properties are functionally related to temperatures as a soil-formation factor.

Threshold Moisture Content (*Biological*). The minimum moisture condition, measured either in terms of moisture content or moisture stress, at which biological activity just becomes measurable.

Tidal Flats. Areas of nearly flat, barren mud, periodically covered by tidal waters. Normally these materials have an excess of soluble salt ; a miscellaneous land type.

Tight Soil. Compact, impervious, and tenacious : usually, plastic soil.

Tile Soil. Concrete or pottery pipe placed at suitable spacings and depths in the soil or subsoil to provide water outlets from the soil.

Till Unstratified, glacial deposits. (*see* Glacial Drift).

Tilth. The physical conditions of soil relative to its response to tillage machinery and its mechanical impedance to root penetration.

Toposequence. A sequence of soils whose properties are functionally related to topography as a soil-formation factor.

Topsoil. (1) The layer of soil moved in cultivation. (*See* Surface Soil) (2) The A horizons. (3) The A_1 horizons. (4) Presumably fertile soil material used to topdress roadbanks, gardens, and lawns.

Transitional Soils. Soils somewhat resembling two different soils and genetically related to them.

Transported Soil (*Obsolete*). Soil formed from unconsolidated sedimentary rocks.

Truncated. Having lost all or part of the upper soil horizon or horizons.

Tuff. Deposited volcanic ash, usually more or less stratified and consolidated.

Tundra Soils. A zonal group of soils having dark-brown highly organic surface horizons over grayish or brownish horizons which rest on cold or ever-frozen substrata ; developed under shrubs and mosses in cold, semiarid to humid climates, *e.g.*, in arctic regions.

U

Ultimate Particles. Soil particles after a standard dispersing treatment.

Underground Runoff (Seepage). Water flowing toward stream channels after infiltration into the ground.

Undifferentiated Soil Groups. Soil-mapping units in which two or more similar taxonomic soil units occur, but not in a regular geographic association. For example, the steep phases of two or more similar soils might be shown as a unit on a map because topography so dominates the properties. (*see* Soil Association ; Soil Complex).

Unsaturated Flow. The movement of liquid water in an unsaturated soil.

Upper Plastic Limit. (*see* Liquid Limit)

Urban-Land. Areas so altered or obstructed by urban works or structures that identification of soils is not feasible. A miscellaneous land type.

V

Value, Color. One of the three variables of color. The relative intensity of the reflected light increases as the value increases. (*see* Munsell Notation).

Variant. (*see* Soil Variant).

Varnish (Desert). A glossy coating on stones, in deserts.

Varves. Distinctly marked annual deposits of sediment regardless of their origin.

Very Coarse Sand. (*see* Soil Separates ; Soil Texture).

Very Fine Sand. (*see* Soil Separates ; Soil Texture).

Volcanic-Ash-Land. Areas of nearly unmodified deposits of valcanic ash so recent that they show little or no evidence of soil development and have little or no vegetation. A miscellaneous land type.

Volume Weight. (*see* Bulk Density).

W

Wasteland. Land not capable of producing materials or services of value. A miscellaneous land type.

Water Conductivity. Hydraulic conductivity as measured with water.

Waterlogged. State of being saturated with water.

Water-Stable Aggregate. A soil aggregate not broken down by agitation in water, usually by wet sieving.

Water Table. The upper surface of ground water ; locus of points in soil water at which the hydraulic pressure is equal to atmospheric pressure.

Water Table, Perched. The upper surface of a body of free ground water in a zone of saturation ; separated, by unsaturated material, from an underlying body of ground water in a different zone of saturation.

Weathering. All physical and chemical changes produced in rocks, at or near the earth's surface, by atmospheric agents, and which result in more or less complete disintegration and decomposition.

Wild Flooding. (*see* Irrigation methods).

Windbreaks. A strip of trees or shrubs serving to reduce the force of wind ; any protective shelter from the wind.

Wilting Point. Same as permanent wilting percentage, as defined in standard plant physiology texts.

X

Xerophytes. Plants that grow in dry sites (soils).

Y

Yield, Sustained. As applied to forest and range management, implies measures which will maintain the productive capacity of the land.

Z

Zymogenic Flora. The flora, usually with one or a few species predominant, developing in soil following the addition of an excess quantity of readily decomposable organic material.

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